PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

VOL. I JULY, 1947 No. 3

Previous issue published April 7, 1947

CONTENTS

PAGE

Utinomi's Bibliographica Micronesica: *Chordate Sections.* HARVEY I. FISHER . . 129

Arsenic Toxicity Studies in Soil and in Culture Solution. HARRY F. CLEMENTS and JEROME MUNSON 151

Factors in the Behavior of Ground Water in a Ghyben-Herzberg System. CHESTER K. WENTWORTH 172

Travel Times of Seismic Sea Waves to Honolulu. BERNARD D. ZETLER . . . 185

NOTES:

New Botanical Bibliography of Pacific Islands by E. D. Merrill 189

Scientists and the Fortieth Anniversary of the University of Hawaii . . . 189

Cover drawing by A. S. MacLeod

PACIFIC SCIENCE, a quarterly publication of the University of Hawaii, appears in January, April, July, and October. Subscription price is three dollars a year; single copies are one dollar. Check or money order payable to University of Hawaii should be sent to PACIFIC SCIENCE, Office of Publications, University of Hawaii, Honolulu 10, Hawaii.

Utinomi's *Bibliographica Micronesica:* Chordate Sections

HARVEY I. FISHER[1]

A COPY OF *Bibliographica Micronesica / Scientiae Naturalis et Cultus,* by Dr. Huzio Utinomi, became temporarily available in the Territory of Hawaii late in the summer of 1946. This bibliography of 208 pages was published in 1944 by the Hokuryūkan Publishing Company in Tokyo. A negative microfilm was made by the University of Hawaii Library, and later certain sections were enlarged and printed photographically.

An interest in the vertebrate animals of Micronesia, especially those of Yap, led me to have certain Japanese titles translated for personal use. It soon became evident that although the bibliography was not complete, it did include many significant titles that had previously been overlooked by workers in vertebrate zoology.

This bibliography has great interest at the present time. Failure to consider scientific papers by Japanese students may be attributed to language difficulties and to lack of knowledge even of the existence of such papers. Apparently few copies of this bibliography can be found outside Japan. Further, interest in the area concerned has been increased greatly by the recent occupation of Micronesia by Americans. Several expeditions and survey parties have been through the islands since the cessation of hostilities. Interest in these new possessions has grown among scientists of the post-war period, and many scientific investigations can be expected in these islands that were formerly under Japanese mandate. In many branches of science it would be inadvisable to start a study without some knowledge of the work carried on by Japanese scientists in the mandated islands.

Because of the above facts it seems desirable to publish immediately all the titles given by Utinomi, and to add translations of the titles and publications cited in the Japanese language. The present paper includes only those sections dealing with chordate animals, and constitutes pages 24 to 43 of the original publication, in addition to the translated Preface and Explanatory Notes.

The list of titles is of course not exhaustive, but it is not the purpose of this publication to add titles to Utinomi's list. A complete bibliography of the chordates in Micronesia would take years of preparation and research in many libraries. The immediate usefulness of the bibliography in its present form, it is hoped, will excuse some incompleteness.

Many difficulties were encountered. One of the most serious was our inability to be absolutely certain of the "accepted" English translations of the Japanese journals and books. The Japanese ideographs may often be interpreted in several ways; each may be literally correct but at the same time may not be the exact wording of the journal's name. For example, the ideograph "Kaiho" may mean either "journal" or "transactions." In one instance we found in the United States Department of Agriculture Miscellaneous Publications No. 337, on abbreviations of titles of publications, that the "*Journal* of the Formosa Natural History Society" was the accepted translation, but on

[1]Department of Zoology and Entomology, University of Hawaii. Manuscript received March 1, 1947.

a copy of this journal the masthead reads "*Transactions* of . . . " Consequently, "Kaiho" has been used consistently as "transactions," but in some cases it probably should mean "journal." "Dōbutsu" means animals, and "Dōbutsugaku" means zoology, but "Dōbutsu" as part of a journal's title may signify zoology. Some English translations of the names of Japanese journals are, however, given in an appendix to the original book (p. 183 ff.). Difficulty of course exists also in translating titles of papers, but for these we have been less concerned in obtaining exact wording, for we felt that a more or less precise indication of content would be sufficient to make the translation markedly useful to others.

Owing to this uncertainty in some translations, we have deemed it advisable to include the Japanese, and in some instances Chinese, characters where they were given in the original. Titles of journals, books, and reports are given in the original characters and in the Hepburn system of Romanization, as well as in explanatory English translation if no accepted translation could be found.

All translations and explanations added by the present author are enclosed in brackets. Brackets in the original have been reduced to parentheses. Volume numbers in the original have been replaced by italics below.

All citations have been left in their original form if this form was understandable; that is, we have not attempted to make uniform the manner in which papers are cited. The original publication contains many typographical errors, misspelled words, and incorrect and omitted diacritical marks. Whenever it could be determined without question that an inaccuracy was present, correction was made. However, inability to check the citation of many titles and their pagination has made it impossible to remedy all such errors.

The use of common names in titles has proved very bothersome. It took, for example, considerable effort to make certain that the two characters meaning "grave" and "builder" referred to megapode birds only and not to various burrowing birds. In some few places we have been forced to use the descriptive common name implied by the Japanese characters, in lieu of a positive scientific name.

I wish to acknowledge gratefully the wholehearted assistance and co-operation of Mr. K. Sakimura of the Pineapple Research Institute in Honolulu and of Miss M. Fukuda and Dr. Y. Uyehara of the University of Hawaii, all of whom worked on the translations from the Japanese. Final decision on the scientific terminology, however, remains the responsibility of the present writer.

Since other members of the faculty of the University of Hawaii are now preparing translations of sections of the bibliography that deal with their specialized fields, it was felt that this first redaction should include Utinomi's Preface and Explanatory Notes to the original book. These are hereinafter given in their entirety in a translation by Dr. Uyehara.

PREFACE

The compilation of this bibliography, as I have previously stated in the first volume of the 1938–39 issue of *Kagaku Nanyō* (*South Sea Science*), is an attempt to collect every possible paper, both native and foreign, on the Japanese-owned South Sea islands. Thus, I may offer materials necessary for the survey of resources and for scientific research on the South Sea islands which constitute the only southern territory of our country, and at the same time may furnish information to those who wish to engage in the study of the science of the South Seas at the Palao Tropical Biological Station.

Five years have elapsed since my announcement of this compilation, but the publication was unavoidably delayed because the

compiler had to serve three years of that time in war duties. However, current developments do not permit me to procrastinate any longer. Although the existing circumstances differ greatly from those of the pre-war period in which this project was started, the value of our South Sea islands has not changed in the least. Moreover, an exhaustive scientific study of these islands as a basis for the development of this region should never be neglected. Hence, I believe the publication of this bibliography now is very timely; and I will be very pleased if it should in any way serve as a guide to scientific research in our South Sea islands. As we note in this collection, the scientific studies made by Japanese scholars since these islands became a territory of Japan are not few. Thus, they are already contributing greatly toward the advancement of South Sea science. The compilation of this bibliography is but the fruit of the efforts of these scholars. I take this opportunity to pay my deepest respects to them.

In this bibliography, all treatises obtainable, from both native and foreign sources, that deal with the sciences (botany, zoology, geology-mineralogy, oceanography, geophysics, medicine, anthropology-ethnology, and geography) relating to the South Sea islands have been included. I have made an effort to list even popular literature, if considered sufficient to serve as good references, bringing the total number to almost four thousand. The greater part of these have been collected by the compiler himself. Furthermore, to insure a greater degree of perfection, various specialists have been asked to assist in the gathering of literature or in revision, as itemized below. However, the scope of the collection is extremely great and owing to lack of a better indexing method on the part of the compiler, there may be more than a few omissions. In filling this gap, I appeal for the co-operation of those who utilize this bibliography; at the same time I hope they will add titles as they see fit.

In presenting this bibliography to the world, I should like to list the names of those who have given me greatest assistance in the compilation of this work, and to express my deepest appreciation for their kind efforts. Moreover, I have been accorded facilities by numerous government offices, universities and colleges, research institutes, libraries, public organizations, and individuals. For want of space, I have not listed their names here; but deep gratitude is due them for their kindness.

BOTANY:[2] Hosokawa, Takahide; Tsuyama, Takashi (Phanerogamae): Tagawa, Motoji (Pteridophyta): Horikawa, Yoshio (Bryophyta): Yamada, Yukio (Algae).

ZOOLOGY: Kuroda, Naganari (Mammalia; Aves): Momiyama, Tokutarō (Aves): Okada, Yaichirō; Oshima, Masamitsu (Reptilia; Amphibia): Abe, Toshiaki (Pisces): Tokioka, Takashi (Protochordata): Kuroda, Tokubei; Baba, Kikutarō (Mollusca): Hayashi, Ryōji (Echinodermata): Oshima, Hiroshi; Murakami, Shirō (Holothuroidea; Ophiuroidea): Miyake, Sadayoshi (Crustacea): Satō, Ikio; Takakuwa, Yoshioki; Takashima, Haruo (Myriapoda; Arachnoidea): Ezaki, Teizō (Insecta): Takahashi, Ryōichi (Hemiptera; Thysanoptera): Tokunaga, Masaaki (Diptera): Kano, Tadao (Coleoptera): Nakamura, Yamato (Lepidoptera): Kobayashi, Shinjirō; Ofuchi, Matatsu (Oligochaeta): Takahashi, Keizō; Okuda, Shirō (Polychaeta): Satō, Hayao (Gephyrea): Ozaki, Yoshimasa; Ogata, Fujiharu (Trematoda): Haneda, Yoshiine (Protozoa): Abe, Noboru (Coelenterata; Zoological Miscellany).

MINERALOGY AND CORAL REEF: Tayama, Rizaburō; Eguchi, Motoki.

OCEANOGRAPHY: Uda, Michitaka.

GEOPHYSICS: Kumagae, Naoichi (Magnetics): Kawasaki, Hideo (Meteorology).

MEDICINE: Haneda, Yata; Medical officers of the Nanyōchō (South Sea Islands Government Office).

ANTHROPOLOGY-ETHNOLOGY: Motoda, Shigeru; Sugiura, Kenichi (Ethnology).

GEOGRAPHY: Wada, Shunji (Geography): Wada, Seiji; Ban, Yoshii (Fishery): Yoshino, Tsuyoshi (Agriculture and Forestry).

[2] Several readings or translations are possible when Japanese names are written in Chinese characters. Hence, popularly accepted pronunciation has been used here whenever actual translation was not possible.–TRANSLATOR'S NOTE.

Lastly, may I express my sincere appreciation to the following persons, who have given me the greatest facilities and authorization possible during all my work: Dr. Keita Shibata, director of the Resource Science Research Institute of the Ministry of Education, Dr. Shikiji Hatai, former director of the Palao Tropical Biological Station, Dr. Takashi Komai, professor at the Kyōto Imperial University, and Dr. Teizō Ezaki, professor at the Kyūshū Imperial University. My sincere thanks are also due to Dr. Yaichirō Okada of the Resource Science Institute and to Mr. Takemori Shintani of the Society for the Promotion of Science in Japan for their assistance in the publication of this work; and to Mr. Ryōtarō Fukuda, president of the Hokuryūkan, who has willingly undertaken the publication of a work of this nature which involves much difficulty in view of the present situation.

JUNE, 1943 THE COMPILER

EXPLANATORY NOTES

1. This collection includes all scientific works obtainable on the South Sea islands, either from periodicals and irregular publications or in book form. Since the subject of the collection lay primarily in the field of natural sciences and secondarily in cultural sciences, thoroughness may be wanting in the latter field.
2. The scope of this collection comprises an area of the southwestern Pacific Islands generally known as Micronesia, limited primarily to the Japanese islands (Marianas, Palao, Carolines, and Marshalls), but including also the adjacent Gilbert and Wake Island groups.
3. The greater portion of the list includes those items which had been published by the end of 1942; however, the compiler has tried his best to include also publications of later dates.
4. The arrangement of the collection under each heading follows an alphabetical order, with the titles of papers appearing in complete form exactly as they are found in the respective publications. The order of each citation is: name of author or compiler, the year of publication, the title, the name of the journal or magazine (abbreviated), the volume, the number, and the page.
5. In case an abstract in a European language is appended to a publication in Japanese, the corresponding title in the European language appears in parentheses after the Japanese title.
6. The volume is given in bold type [in italics now] and the number in small type. In instances in which the issue number and the individual volume number are likely to be confused, "no." is written before the former.
7. When the author or compiler's name is not mentioned, "———" is used to indicate such an omission, and the works have been arranged in chronological order at the end of every heading.
8. Page number in brackets [in parentheses now] indicates that that page should be referred to in relation to particular headings or subjects.
9. When a Japanese journal or magazine has titles in both Japanese and a European language, the title used is in Japanese if the paper is in Japanese, and in the European language if the work is in that language.
10. The complete names of the journals and magazines used in abbreviated forms are listed in the appendix.
11. Dates of publications are all according to the Western calendar; and to facilitate references, a table indicating Japanese chronology as compared to that of the West is inserted at the end of the book.

[CHORDATE SECTIONS]

2. 哺 乳 類 (Mammalia)

ANDERSON, K. 1908 Twenty new forms of *Pteropus*. Ann. Mag. Nat. Hist., ser. 8, 2, pp. 361–370.

—— 1912 Catalogue of the Chiroptera in the Collection of the British Museum. Second Edition. Vol. I. Megachiroptera. (pp. 172–180, 275–279, 295–310, 797–798) Brit. Mus. (Nat. Hist.), London.

淺野長雄 [ASANO, N.] 1938 パラオの儒艮に就て、[On the Dugong of Palau]. 植物及動物[Shokubutsu oyobi Dōbutsu, or Botany and Zoology], 6, 6, pp. 1047–1051; 7, pp. 1219–1228.

BRANDT, J. F. 1835 Prodomus descriptionis animalium ab H. MERTENSIO in orbis terrarum circumnavigatione observatorum. Fasc. I. Petropoli. (pp. 42–61, 73–75)

CUVIER, G. 1821–1824 Osoements fossiles. 2 ed., IV. (p. 45)

DESMAREST, A. 1822 Mammalogie. II, Suppl. (p. 547) Paris.

DOBSON, G. E. 1878 Catalogue of the Chiroptera (in the Collection of the British Museum). (pp. 63–64, 360–361) Brit. Mus. (Nat. Hist.), London.

FREYCINET, L. de 1825 Voyage autour du monde exécuté sur les corvettes de S. M. l'Uranie et la Physicienne, pendant les années 1817–1820. Historique, *II*, 1. (p. 271) Paris.

GIEBEL, C. G. 1855 Säugethiere. (p. 998) Berlin.

GRAY, J. E. 1870 Catalogue of Monkeys, Lemurs, and Fruit-eating Bats in the Collection of the British Museum. (pp. 107–109) Brit. Mus. (Nat. Hist.), London.

HAMILTON-SMITH, [?] 1827 GRIFFITH'S Animal Kingdom. (IV, p. 115; V, p. 311)

平坂恭介 [HIRASAKA, K.] 1939 泳ぐ人魚 [Dugongs That Swim]. 臺灣水產雜誌 [Taiwan Suisan Zasshi, or Formosan Fisheries Magazine], 286, pp. 1–4.

—— 1939 パラオの儒艮、[Dugongs of Palau]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *2*, 2, pp. 69–76.

—— 1942 人魚雜話 [Tales of Dugongs]. 民族臺灣 [Minzoku Taiwan, or Formosan Ethnology], *2*, 10, pp. 6–7.

HOMBRON, J. B. & JACQUINOT, C. H. 1843 Voyage au Pole Sud et dans l'Oceanie sür les corvette l'Astrolabe et la Zélée; exécuté par ordre du Roi, pendant les années 1837–1840. Zoologie, Atlas, III.

堀井榮吉[HORII, E.] 1916 新領土南洋諸島動物調査報告 [Report on the Zoological Investigations or Survey of the South Sea Islands, the New Territory] 南洋新占領地視察報告 [Nanyō Shinsenryōchi Shisatsu Hōkoku, or The Survey Report on the South Sea Islands, the New Territory], pp. 234–266 (pp. 235–236); 委任統治地域南洋群島調査資料 (1927) [Inin Tōchi Chiiki Nanyōguntō Chōsa Shiryō, or Data on the Investigation of the Newly Occupied South Sea Islands (1927)], *I*, pp. 245–281. (pp. 246–247)

JACQUINOT, C. H. & PUCHERAN, J. 1846 Voyage au pole sud et dans l'oceanie sur les corvette l'Astrolabe et la Zélée; exécuté par ordre du Roi, pendant les années 1837–1840. Zoologie, t. *III*. Mammifères et Oiseaux.

岸田久吉(KISHIDA, K.) 1924 哺乳動物圖解 (Monograph of Japanese Mammals). 381, pp. 日本鳥學會特別出版 [Special Publication of the Ornithological Society of Japan]. (再版, 1926) [Second Edition, 1926]

黑田長禮(KURODA, N.) 1920 籾山氏採集南洋產哺乳類[Mammals of the South Sea Islands Collected by Mr. Momiyama]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *32*, 380, pp. 199–208.

—— 1920 南洋產哺乳類雜記 [Miscellaneous Reports on the Mammals of the

South Sea Islands]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *32*, 382, pp. 261–263.

——— 1930 小笠原群島產哺乳類[Mammals of the Bonin Islands]. 日本生物地理學會々報[Nippon Seibutsu Chirigaku Kai Kaihō, or Transactions of the Zoogeographical Society of Japan], *1*, 3, pp. 82–84.

——— 1934 山階侯爵家所藏南洋產鼠類 [Rodents of the South Sea Islands in the Collection of Marquis Yamashina].

植物及動物[Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *2*, 6, pp. 1012–1020.

——— 1937 哺乳類 [Mammalia]. (pp. 78–79) 脊椎動物大系 [*in* Sekitsui Dōbutsu Taikei, published by Sanseidō, Tokyo]. 三省堂, 東京[Taxonomy of Vertebrate Animals].

——— 1938 A List of the Japanese Mammals, including Saghalien, Korea, Formosa and Micronesia (日本產哺乳類目錄), 122 pp. Author's ed., Tokyo.

——— 1939 Distribution of Mammals in the Japanese Empire. Jour. Mamm., 20, 1, pp. 37–50. (pp. 46–47)

——— 1940 — 眼豚 [Porpoises?]. 動物文學 [Dōbutsu Bungaku, or Zoological Literature], 7, 5, pp. 41–42.

——— 1940 ポナペ島產挿尾蝙蝠に就て[On *Emballonura semicaudata* Yamashina from Ponape]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *8*, 4, pp. 762–763. (江崎教授ミクロネシア探檢報告, No. 39) [Professor Esaki's Report No. 39 on Micronesian Expedition].

——— 1940 原色日本哺乳類圖說 A Monograph of the Japanese Mammals (exclusive of Sirenia and Cetacea) 311 pp. 三省堂, 東京. [Published by Sanseidō, Tokyo].

MATSCHIE, P. 1899 Die Fledermäuse des Berliner Museums für Naturkunde. pt. I. Die Megachiroptera. 8 vo., 103 pp., 14 pls. (p. 27) Berlin.

MILLER, G. S. JR. 1907 The Families and Genera of Bats. U. S. Nat. Mus., Bull. 57, (p. 58)

——— 1911 A new Bat from the Caroline Islands. Proc. Biol. Soc. Wash. 24, pp. 161–162.

籾山德太郎[MOMIYAMA, T.] 1920 大蝙蝠の習性其他 [Habits and Behavior of Fruit Bats]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *32*, 382, pp. 263–264.

森 小辨[MORI, S.] 1936 椰子樹の鼠害 [Rat Damage to Coconut Palms]. 南島群島 [Nanyō Guntō, or South Sea Islands], *2*, 2, pp. 50-55, 69.

波江元吉[NAMIE, M.] 1915 パラオ石灰洞中の蝙蝠 [Bats Found in the Limestone Caves in Palau]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], 27, 325, pp. 600–601.

尾形藤治[OGATA, T.] 1942 南海の人氣者——人魚 [The Popular Appeal of the South Sea Dugong]. 黒潮 [Kuroshiwo, or Japan Current], *5*, 10, pp. 26–32; 12, pp. 76–83.

——— 1943. パラウサシヲカウモリ (*Emballonura semicaudata palauensis* YAMASHINA) に就て [On *Emballonura semicaudata palauensis*, Yamashina]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *11*, 2, pp. 175-177.

大島 廣[OSHIMA, H.] 1942 儒艮 [Dugongs]. 圖解科學 [Zukai Kagaku, or Illustrated Science], *1*, 7, pp. 19–25.

OKADA, Y. (岡田彌一郎) 1938 A Catalogue of Vertebrates of Japan (日本脊椎動物目錄). 412 pp. (Mammalia: pp. 1–25) Maruzen, Tokyo.

王 雨 鄉、高島春雄 [O, U., TAKASHIMA, H.] 1938 日本產翼手目資料 [Data on the Chiroptera of Japan]. 臺灣博物學會々報 [Taiwan Hakubutsugaku Kai Kaihō, or Transactions of the Natural History Society of Formosa], *28*, 176, pp. 162–175.

DUSTALET, M. E. 1895–96 Les Mammifères et les Oiseaux des les Mariannes. Nouv. Arch. Mus. Hist. Nat., sér. 3, *7*, pp. 141–228; *8*, pp. 25–75.

PETERS, W. 1867 Ueber die Flederhunde, Pteropi und insbesondere über die Arten der Gattung *Pteropus* s.s. Monatsber. Akad. Wiss. Berlin, 1867, p. 480.

—— 1869 Ueber neue oder weniger bekannte Flederthiere, insbesondere des Pariser Museums. Monatsber. Akad. Wiss. Berlin, 1869, pp. 326, 331, 391.

—— 1883 Ueber die von Herrn Dr. FINSCH von den Carolinen Inseln eingesandten Flederhunde. Sitzber. Ges. Naturforsch. Freunde, Berlin, *1*.

QUOY, J. R. C. & GAIMARD, P. J. 1824 Voyage autour du monde, exécuté sur les Corvettes de S.M. l'Uranie et la Physicienne, pendant les années 1817–1820. Zoologie. (pp. 32, 51, Atlas 3) Paris.

—— 1825 Notice sur les mammifères et les oiseaux des iles Timor, Rawak, Boni, Vaigiou, Guam, Rota et Tenian. Ann. Sci. Nat., Zool., *6*, pp. 138–150.

—— 1833 Voyage de découvertes de la corvette l'Astrolabe, exécuté par ordre du Roi, pendant les années 1826–1829. Zoologie, *1*. (p. 74, pls. 8–9) Paris.

SCHNEE, P. 1904 Die Landfauna der Marshall-Inseln nebst einigen Bemerkungen zur Fauna der Insel Nauru. Zool. Jahrb., Abt. Syst.; *20*, 4, pp. 387–412.

—— 1911 Die verwilderten Haustiere auf Tinian. Zeits. Kolonialpoli-tik, *13*, pp. 350–362.

鹿間時夫[SHIKAMA, T.] 1942 ポナペ島の鹿について [On the Deer of Ponape]. 日本生物地理學會々報 [Nippon Seibutsu Chirigaku Kai Kaihō, or Transactions of the Zoogeographical Society of Japan], *12*, 6, pp. 97–103.

TATE, G. H. H. 1934 Bats from the Pacific Islands, including a new fruit bat from Guam. Amer. Mus. Novit., *713*, pp. 1–3.

—— 1935 Rodents of the genera *Rattus* and *Mus* from the Pacific Islands, collected by the Whitney South Sea Expedition, with a discussion of the origin and races of the Pacific Island rat. Bull. Amer. Mus. Nat. Hist., *68*, 3 pp. 145–178.

TEMMINCK, G. J. 1825 Monographies de Mammalogie. *I*. (p. 186)

THOMAS, O. 1882 Description of two new species of *Pteropus* from the Caroline Islands. Proc. Zool. Soc. London, 1882, pp. 755–757.

TOKUDA, M. (徳田御稔) 1933 On some rats and mice from the South Sea Islands. (Part I. *Rattus concolor* Group). Annot. Zool. Jap., *14*, 1, pp. 79–37 [sic].

—— 1941 日本及び滿洲産鼠類の分類 [Classification of the Rodents of Japan and Manchuria], (摘要) [Resumé], 鼠類に見られる變異の檢討 [Variation of Rodents]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *53*, 6, pp. 287–298.

—— 1941 A Revised Monograph of the Japanese and Manchou-korean Muridae. Biogeographica, *4*, 1, pp. 1–155; Yokendo, Tokyo.

TROUESSART, E. L. 1879 Catalogue des Mammifères vivants et fossiles. Rev. & Mag. Zool., sér. 3, *6*. (p. 203)

内田 亨[UCHIDA, T.] 1935 テニアン島の野牛 [On the Wild Cattle of Tinian]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *3*, 3, pp. 639–640.

WAGNER, [?] 1853–1855 SCHREBER'S Säugethiere. V. (pp. 600, 698)

渡邊菊治 [WATANABE, K.] 1937 野鼠及び野鼠チブス菌に關する研究 [Studies on Field Mice and Typhus Disease]. 茨城縣農事試驗場, 臨時報告 [Ibaragi Ken Nōji Shikenjō Rinji Hōkoku, or Special Report of the Ibaragi Agricultural Experiment Station], *2*, pp. 1–174.

山階芳麿(YAMASHINA, Y.) 1932 邦領南洋諸島産蝙蝠の新亞種 (On new bats found

in Polynesian region, (Japanese Mandate) 臺灣博物學會會報 [Taiwan Hakubutsugaku Kai Kaihō, or Transactions of the Natural History Society of Formosa], *22*, 121, pp. 240–241.

谷津直秀 [TANIZU, N.] 1917 第十一 片々錄——儒艮[Number 11, Occasional Papers—Dugong]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *29*, 345, p. 223.

3. 鳥 類(Aves)

BENNETT, F. D. 1840 Narrative of the whaling Voyage, I.

BONAPARTE, C. R. 1850 *Chalcopsitta rubiginosa.* Conspectus Generum Avium, 1. (p. 3.)

——— 1854 (*Metabolus*, sp. nov.) C. R. Acad. Sci. Paris, 38, p. 650.

DESMAREST, A. G. 1826 *Columba oceanica.* Dictionaire des Science Naturelles, Levrault, XL, p. 316.

DUBOIS, A. 1902 Synopsis Avium, Nouveau manuel d'Ornithologie, X–XII, pp. 689–914. (p. 711)

DUMONT, D'URVILLE, J. 1823 *Alcedo albicilla.* Dictionaire des Science Naturelles, Levrault, XXIX, p. 273.

ELLIOT, D. G. 1878 On the Fruit-Pigeons of the Genus *Ptilopus*. Proc. Zool. Soc. London, 1878, pp. 500–575. (pp. 516, 531, 535, 537)

FINSCH, O. 1875 Characters of six new Polynesian Birds in the Museum Godeffroy, at Hamburg. Proc. Zool. Soc. London, 1875, pp. 642–644.

——— 1875 Zur Ornithologie der Südsee-Inseln. I. Die Vögel der Palau-Gruppe. Jour. Mus. Godeffr., *3*, 8, pp. 133–183.

——— 1876 Zur Ornithologie der Südsee-Inseln. II. Ueber neue und weniger bekannte Vögel von den Viti-, Samoa-, und Carolinen-Inseln. Jour. Mus. Godeffr., *5*, 12, pp. 15–40.

——— 1876 Über den Schwalbenwürger (*Artamus*) der Palau Inseln. Jour. Mus. Godeffr., *5*, 12, pp. 41–42.

——— 1877 On the Birds of the Island of Ponapé, Eastern Carolines. Proc. Zool. Soc. London, 1877, pp. 777–782.

——— 1880 'Beobachtungen über die Vögel der Insel Ponapé, Kuschai, Carolines. Jour. Ornith., *28*, pp. 283–310.

——— 1880 A List of the Birds in the Island of Ruk in the Central Carolines. Proc. Zool. Soc. London, 1880, pp. 574–577.

——— 1880 On two species of Pigeons from the Caroline Islands. Proc. Zool. Soc. London, 1880, pp. 577–578.

——— 1880 Ornithological Letters from the Pacific. II–III. Ibis, 4th ser., *4*, pp. 218–220; pp. 329–333.

——— 1881 Ornithological Letters from the Pacific. V–VI, Ibis, 4th ser., *5*, pp. 102–115.

——— 1884 Dritte allgemeine Ornithologische Ausstellung in Wien. Mitt. Ornith. Ver. Wien, 1884, p. 72.

——— 1884 Ueber Vögel der Südsee. Mitt. Ornith. Ver. Wien, 1884, (pp. 54, 55, 75, 76, 92–95, 108–111 & 120–127)

——— 1901 Das Tierreich. 15 Lief. Zosteropidae.

FINSCH, O. & HARTLAUB, G. 1867 Beiträge zur Fauna Centralpolynesiens. Ornithologie der Viti-, Samoa- und Tonga-Inseln. Halle, Roy. 8 vols. 290 pp., 14 pls. (p. 109)

FORBES, W. A. 1879 A Synopsis of the Meliphagine Genus *Myzomela*. Proc. Zool. Soc. London, 1879, pp. 256–278. (p. 270)

GRAY, G. R. 1852 (*Ptilonopus purpureocinctus*) Proc. Zool. Soc. London, 1853, p. 48.

——— 1859 Catalogue of the Birds of the Tropical Islands of the Pacific Ocean, in the Collection of the British Museum. Brit. Mus. (Nat. Hist.), London.

Hachisuka, M. U. ·(蜂須賀正氏) 1939 New Races of a Rail and a Fruit Pigeon from Micronesia and Palawan. Bull. Brit. Ornith. Club, *59*, 424, pp. 151–153.

—— 1939 The Red Jungle Fowl from the Pacific Islands. Tori, *10*, 49, pp. 596–601.

Hachisuka, M. U., Kuroda, N., Takatsukasa, N., Uchida, S. & Yamashina, Y. (蜂須賀正氏、黒田長禮、鷹司信輔、内田清之助、山階芳麿) 1932 A List of the Birds of Micronesia under Japanese Mandatory Rule (我委任統治南洋諸島產鳥類目錄) in: A Hand-List of the Japanese Birds. Revised (改訂、日本鳥類目錄), pp. 167–199. 日本鳥學會刊行 (3rd & revised edition, 1942)

Hartert, E. 1891 *Kittlitzia*, n. gen. Katalog der Vögelsammlung in Museum der Senckenbergischen Naturforschenden Gesellschaft in Frankfurt am Main. (pp. 75–76)

—— 1897 On a new species of *Tephras* (Zosteropidae) from the Caroline Islands. Bull. Brit. Ornith. Club, *7*, 47, p. 5.

—— 1898 On the Birds of the Marianne Islands. Nov. Zool., *5*, 1, pp. 51–69.

—— 1900 The birds of Ruk in the Central Carolines. Nov. Zool., *7*, 1, pp. 1–11.

—— 1917 On some Rallidae. Nov. Zool., *24*, pp. 265–274. (p. 268)

—— 1926 Types of birds in the Tring Museum. B. Types in general collection. VII. Tubinares. Nov. Zool., *33*, 3, pp. 344–357.

—— 1927 Types of birds in the Tring Museum. B. Types in general collection. VIII. Columbae-Struthionidae. Nov. Zool., *34*, 1, pp. 1–38.

Hartlaub, G. 1852 Tinian Peales Vögel der "U.S. Exploring Expedition." Arch. Naturg., Abt. A., *18*, pp. 93–138. (p. 131)

—— 1854 Zur Ornithologie Oceanien's. Jour. Ornith., *2*, pp. 160–171.

—— 1865 Monographischer Versuch über die Gattung *Zosterops*. Jour. Ornith., *13*, pp. 1–30.

—— 1867 On a collection of Birds from some less-known localities in the western Pacific. Proc. Zool. Soc. London, 1867, pp. 828–832.

—— 1869 Katalog des Museum Godeffroys. IV.

—— 1874 Katalog des Museum Godeffroys. V.

—— 1892 Vier selten Rallen. Abh. Nat. Ver. Bremen, *12*, 3, pp. 389–402. (p. 391)

Hartlaub, G. & Finsch, O. 1868 On a collection of Birds from the Pelew-Islands. Proc. Zool. Soc. London 1868, pp. 4–9.

—— —— 1868 Additional Notes on the Ornithology of the Pelew Islands. Proc. Zool. Soc. London, 1868, pp. 116–118.

—— —— 1872 On a fourth Collection of Birds from the Pelew and Mackenzie Islands. Proc. Zool. Soc. London, 1872, pp. 87–114.

Henninger, J. 1912 Ein Beitrag zur geographischen Verbreitung der beiden Pazifischen *Numenius* Arten. Ornith. Monatsber., *20*, pp. 62–64.

土方久功 [Hijikata, H.] 1940 南洋の鳥景(一)[Birds of the South Seas. I.] 野鳥 [Notori, or Field Birds], *7*, 2, pp. 82–84.

—— 1940 ヘレン島、[Helen Island]. 野鳥[Notori, or Field Birds], *7*, 5, pp. 313–316.

Hombron, J. B. & Jacquinot, C. H. 1841 Description de plusieurs Oiseaux nouveaux ou peu connus, provenant de l'expédition autour du monde faite sur les corvettes l'Astrolabe et la Zélée. Ann. Sci. Nat., Zool. (2) *16*, pp. 312–320.

堀井菜吉 [Horii, E.] 1916 新領土南洋諸島動物調查報告書[Report on the Zoological Investigations or Survey of the South Sea Islands, the New Territory]. 南洋新占領地視察報告 [Nanyō Shinsenryōchi Shisatsu

Hōkoku, or The Survey Report on the South Sea Islands, the Newly Occupied Territory], pp. 234–266 (pp. 236–238, 264); 委任統治地域南洋群島調査資料 [Inin Tōchi, Chiiki Nanyōguntō Chōsa Shiryō (1927), or Data on the Investigation of the Occupied South Sea Islands (1927)], *I*, pp. 245–281. (pp. 247–249, 279)

JACQUINOT, C. H. & PUCHERAN, J. 1846 (–53) Voyage au Pole Sud et dans l'Oceanie, sur les Corvette l'Astrolabe et la Zélée; exécuté par ordre de Roi, pendant les années 1837–1840. Zoologie, t. III. Mammifères et Oiseaux. Atlas (1853).

岸田久吉 [KISHIDA, H.] 1929 ムクドリをサイパン島に採集す [The Grey Starling, *Spodiopsar cineraceus*, Collected on Saipan]. Lansania, *1*, 2, pp. 17–18.

北村信昭 [KITAMURA, N.] 1935 パラオ島に於ける動物の鳴聲[Sounds of the Animals on Palau]. 動物文學 [Dōbutsu Bungaku, or Zoological Literature], *11*, p. 35.

KITTLITZ, F. H. von 1832–33 Küpfertafeln zur Naturgeschichte der Vögel. pt. *I* (1832); pt. *II* (1833).

——— 1835 Über einige noch unbeschreibene Vögel von der Insel Luzon, den Carolinen und den Marianen. Mém. Acad. Imp. Sci. St. Pétérsbourg, *2*, pp. 1–9. (p. 6)

——— 1858 Denkwürdigkeiten einer Reise nach den russischen Amerika, nach Mikronesien und durch Kamtschatka, II. (pp. 26, 30).

KRAUSE, R. & SCHMHLTZ [sic], J. D. E. 1881 Die ethnographisch-anthropologische Abtheilung des Museum Godeffroy in Hamburg.

黒田長禮 (KURODA, N.) 1915 新占領獨領南洋諸島産鳥類に就て [On the Birds of the Newly Occupied South Sea Islands]. サイエンス [Saiensu, or Science], *5*, 5, pp. 198–202.

——— 1915 第一回採集新占領南洋諸島産鳥類[First Collection of Birds from the Newly Occupied South Sea Islands]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *27*, 320, pp. 325–332.

——— 1915 第二回採集新占領南洋諸島産鳥類 [Second Collection of Birds from the Newly Occupied South Sea Islands]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *27*, 321, pp. 389–392.

——— 1916 南洋諸島産鳥類ノ二新亞種ニ就テ(On two new subspecies of Birds from the South Sea Islands). 鳥 [Tori, or Birds], *1*, 2, pp. 56–59.

——— 1916 南洋諸島採集鳥類追加 [Additions to the Birds Collected from the South Sea Islands]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *28*, 328, pp. 68–71.

——— 1922 Descriptions of two new forms of Birds from Pelew Islands, Micronesia. In: MOMIYAMA's Birds of Micronesia, pp. 25–30.

——— 1922 南洋諸島産鳥類目錄 (A List of the Birds of Micronesian Group, exclusive of Magalhaes, Gilbert and Ellice Islands). In: MOMIYAMA's Birds of Micronesia, pp. 31–78.

——— 1927 A List of the Birds described by the Author during the ten years from 1915 to 1925, with descriptions of two new forms. Ibis, 12th ser., *3*, 4, pp. 691–723. (pp. 706–707, 719)

——— 1931 南洋諸島産鳥類目錄に新追加四種 [Four Species Newly Added to the List of Birds of the South Sea Islands]. Amoeba, *3*, 3, p. 24.

——— 1932 A Revision of the Types of Birds described by Japanese Authors during the years 1923 to 1931. Nov. Zool., *37*, pp. 384–405.

——— 1933 鳥類總說 [General Treatise on Birds]. 水產動植物圖說 [Suisan Doshokubutsu Zusetsu, or Illustrated Marine Life], pp. 13–69. 大地書院, 東京

Daichi Shoin [publisher's name], Tokyo.

—— 1933–34 鳥類原色大圖說 [Birds in Life Colors]. 3 vols. (*I*, Oct. 1933; *II*, Jan. 1934; *III*, Mar. 1934)

—— 1934 オホキアシシギ(新稱)に就て [A Charadriiform (A New Name?)]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *46*, 549, p. 313.

—— 1941 マリアナガモの研究、 [On Oustalet's Grey Duck of the Marianas]. 鳥 [Tori, or Birds], *11*, 51/52, pp. 99–119.

—— 1942 パラオ諸島產鳥類の新產地 [New Locality Records for the Birds of Palau]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *10*, 1, p. 78.

—— 1943 マリアナガモの研究(第二) [On Oustalet's Grey Duck of the Marianas: Second Report]. 鳥 [Tori, or Birds], *11*, 53/54, pp. 443–448. (發行日附は1942) [listed date of publication, 1942].

LESSON, R. P. 1827. Dictionaire des Science Naturelles, *I*. (p. 30)

—— 1829 Voyage autour du monde, exécuté par ordre du Roi, sur la corvette de sa Majesté La Coquille, pendant les années 1822–1825. Zoologie, t. II.

—— 1831 Traité d'Ornithologie, ou description des Oiseaux réunis dans les principaies collection de France. 8 vols. (p. 472)

LISTER, J. J. 1911 The Distribution of the Avian Genus *Megapodius* in the Pacific Islands. Proc. Zool. Soc. London, 1911, pp. 749–759.

—— 1911 On the Distribution of the Megapodiidae in the Pacific. Proc. Cambridge Phil. Soc., *16*, pp. 148-149.

MARCHE, A. 1891 Raport general sur une mission aux iles Mariannes. Archives des Missions, *17*.

MATHEWS, G. M. 1925 *Monarcharses*, gen. nov. Bull. Brit. Ornith. Club, 45, *296*, p. 94.

—— 1926 On some changes in names. *Nycticorax caledonicus pelewensis*, subsp. nov. Bull. Brit. Ornith. Club, *46*, 302, p. 60.

—— 1927–30 Systema Avium Ausfralasianarum [Australasianarum] (A Systematic List of the Birds of the Australasian Region). 2 pts. (*I*, Jun. 1927; *II*, July 1930) British Ornithologists' Union.

—— 1931 Additions and Corrections to the 'Systema Avium Australasianarum.' Ibis, 13th Ser:, *1*, pp. 44–57.

—— 1932 Additions and Corrections to the 'Systema Avium Australasianarum.' pt. II. Ibis, 13th ser., *2*, pp. 132–161.

—— 1933 Additions and Corrections to the 'Systema Avium Australasianarum.' pt. III. Ibis, 13th ser., *3*, pp. 87–97.

—— 1934 A Check-List of the Order *Procellariiformes*. Nov. Zool., *39*, pp. 151–206.

—— 1938 *Aplornis* versus *Aplonis*. Ibis, 14th ser., *2*, p. 342.

MATSCHIE, P. 1901 Bermerkungen zur Zoogeographie des westlichen Mikronesiens. Jour. Ornith., 1901, pp. 109–114.

MAYAUD, N. 1938 Some Notes on Shearwaters. Ibis, 14th ser., *2*, pp. 343–345.

MAYR, E. 1931 Birds collected during the Whitney South Sea Expedition. XII. Notes on *Halcyon chloris* and some of its subsp[e]cies. Amer. Mus. Novit., *469*, pp. 1–10. (pp. 2–3)

—— 1931 The Parrot Finches (Genus *Erythrura*). Amer. Mus. Novit., *489*, pp. 1–10. (p. 4)

—— 1931 *Rhamphozosterops sanfordi* gen. et spec. nov. Ornith. Monatsber., *39*, 6, p. 182.

—— 1931 Birds collected during the Whitney South Sea Expedition. XVI. Notes on Fantails of the Genus *Rhipidura*. Amer. Mus. Novit., *502*, pp. 1–21.

—— 1933 *Rhamphozosterops* versus *Cinnyrhyncha*. Ibis, 13th ser., *3*, pp. 389–390.

——— 1933 Birds collected during the Whitney South Sea Expedition. XXIII. Two New Birds from Micronesia. Amer. Mus. Novit., *609*, pp. 1–4.

——— 1933 Die Vogelwelt Polynesiens. Mitt. Zool. Mus. Berlin, *19*, pp. 306–323.

——— 1935 Birds collected during the Whitney South Sea Expedition. XXX. Descriptions of Twenty-five new Species and Subspecies. Amer. Mus. Novit., *820*, pp. 1–6. (p. 3)

——— 1936 Birds collected during the Whitney South Sea Expedition. XXXI. Descriptions of Twenty-five Species and Subspecies. Amer. Mus. Novit., *828*, pp. 1–19. (pp. 11–12)

MEARNS, E. A. 1909 A List of Birds collected by Dr. PAUL BARTSCH in the Philippine Islands, Borneo, Guam and Midway Island, with descriptions of three new Forms. Proc. U. S. Nat. Mus., *36*, pp. 463–478. (p. 476)

MOMIYAMA, T. T. 籾山徳太郎 1920 Description of a new subspecies of *Aplonis* from the Islands of the Western Micronesia. Tori, *2*, 9, pp. 1–3 (Eng. colm.).

——— 1922 邦領南洋諸島産鳥類 (Birds of Micronesia). 附、黒田長禮編 南洋諸島産鳥類目錄 [Appendix. Kuroda, N. A List of the Birds of Micronesian Group exclusive of Magalhaes, Gilbert and Ellice Islands]. IV + 8 + 350 + 5 pp.; 78 pp. 日本鳥學臨時刊行 [Spec. Publ. of Jap. Ornith. Soc.].

——— 1926 濟州島産鳥類の採集品に就て(一)[On a Collection of Birds from Saishū Island]. 鳥 [Tori, or Birds], *5*, 22, pp. 10–126. (pp. 108–110)

——— 1932 鳥類分布より見たる紅頭嶼の地位[Status of Botel Tobago from the Standpoint of Bird Distribution]. 日本生物地理學會々報 [Nippon Seibutsu Chirigaku Kai Kaihō, or Transactions of the Zoogeographical Society of Japan], *2*, 3, pp. 251–350 (pp. 333–334, 337); 紅頭嶼生物相[Botel Tobago Seibutsu So, or Fauna and Flora of Botel Tobago], pp. 175–274. (pp. 257–258, 261)

——— 1933 紅頭嶼産鳥類並に其分布系統 (On the Birds of Botel Tobago with their Affinity) 東亞鳥學彙報 [Tōa Chōgaku Kihō, or Miscellaneous Notes on the Ornithology of Eastern Asia], *2*, 1, pp. 1–115 (pp. 83, 84, 87)

MURPHY, R. C. 1928 Birds collected during the Whitney South Sea Expedition. IV. (*Procellariidae, Hydrobatidae*). Amer. Mus. Novit., *322*, pp. 1–5.

NEHRKORN, A. 1879 Mittheilungen über Nester und Eier des Museum Godeffroy zu Hamburg. Jour. Ornith., *27*, pp. 393–410.

NEUMANN, O. 1922 Neue Formen aus dem papuanischen und polynesischen Inselreich. Verh. Ornith. Ges. Bayern, *15*, 2, pp. 234–237.

OBERHOLSER, H. C. 1912 A revision of the forms of the Edible-nest Swiftlet, *Collocalia fuciphaga* (Thunberg). Proc. U. S. Nat. Mus., *42*, pp. 11–20.

——— 1912 A revision of the subspecies of the Green Heron (*Butorides virescens* (Linn.)). Proc. U. S. Nat. Mus., *42*, pp. 529–577.

尾形藤治 [OGATA, T.] 1942 南洋紀行(五) [An Account of a Journey through the South Sea Islands (5)] (五)白尾熱帶鳥 [(5) The White-tailed Tropic Bird]. 町田報德 [Machida, Hōtoku], *85*, pp. 2–4.

——— 1942 南洋紀行(八) [An Account of a Journey through the South Sea Islands (8)]. (八)南洋の鳥 [(8) Birds of the South Seas]. 町田報德 [Machida, Hōtoku], *89*, pp. 2–4.

小川三紀 [OGAWA, S.] 1905 南洋にて採集せられたる日本の鳥 [Birds of Japan Collected in the South Sea Islands]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *17*, 198, pp. 73–80.

大原重明 [OHARA, S.] 1940 サイパン島へ

移入の臺灣鳥は何種？ [The Number of Species of Formosan Birds Introduced to Saipan]. 鳥 [Tori, or Birds], *10*, 48, pp. 441–442.

OKADA, Y. (岡田彌一郎) 1938 A Catalogue of Vertebrates of Japan (日本脊椎動物目錄) 412 pp. (Aves: pp. 26–96) Maruzen, Tokyo.

OUSTALET, M. E. 1881 Notes d'Ornithologie.——2° Observations sur divers oiseaux de l'Asie et de la Nouvelle-Guinée. Bull. Soc. Philom. Paris, (7) *5*, 2, pp. 71–80. (pp. 73, 76)

——— 1881 Monographie des Mégapodiidés. Ann. Sci. Nat., Zool., (7) *11*, pp. 1–182. (pp. 138–140)

——— 1889 Note sur la Faune Ornithologique des Iles Mariannes. Le Naturaliste, (2) *3*, pp. 260–261.

——— 1891 Note sur la Mégapode de LA PÉROUSE. Ann. Sci. Nat., Zool., (7), *11*, p. 196.

——— 1895–96 Les Mammiféres et les Oiseaux de iles Mariannes. Nouv. Arch. Mus. Hist. Nat., sér. 3, 7, (1895), pp. 141–228; *8* (1896), pp. 25–75.

PELZERN, A. 1865 Reise der österreichischen Fregatte Novara (Vögel).

PETERS, J. L. 1930 Notes on some Night Herons. Proc. Boston Soc. Nat. Hist., *39*, 7, pp. 263–277. (pp. 271–272)

——— 1931 Check-List of Birds of the World. vol. I.

——— 1934 Check-List of Birds of the World. vol. II.

——— 1937 Check-List of Birds of the World. vol. III.

PETERS, J. L. & GRISCOM, L. 1928 A New Rail and a New Dove from Micronesia. Proc. New England Zool. Club, *10*, pp. 99–106. (pp. 104–106)

PUCHERAN, J. 1853 Voyage zu pole sud et dans l'océanie, sur les corvette l'Astrolabe et la Zélée; exécuté par ordre du Roi, pendant les années 1837–1840. Zoologie, t. III.

QUOY, J. R. C. & GAIMARD, P. J. 1824 Voyage autour du monde, exécuté sur les Corvettes de S. M. l'Uranie et la Physicienne, pendant les années 1817–1820. Zoologie. (p. 127)

——— 1825 Notice sur les mammiféres et les oiseaux des iles Timor, Rawak, Boni, Vaigiou, Guam, Rota et Tinian. Ann. Sci. Nat. Zool., *6*, pp. 138–150.

——— ——— 1830 Voyage de Découvertes de la Corvette l'Astrolabe exécuté par ordre du Roi, pendant les années 1826–1829. Zoologie, t. I. (p. 202)

REICHENOW, A. 1885 Bericht über die Januar-Sitzung. Jour. Ornith., *33*, pp. 108–110.

——— 1899 On the Migration of Ducks to the Marshall Islands. Ornith. Monatsber., 7, p. 41.

——— 1901 Eine auffallende Vogelzugstrasse vom nordwestlichen Nordamerika nach Polynesiën. Ornith. Monatsber., *9*, pp. 17–18.

——— 1902 Vögel von Nauru. Jour. Ornith., *50*, 5, p. 254.

——— 1915 Neue Arten. (*Cleptornis palauensis* subsp. nova.) Jour. Ornith., *63*, pp. 124–129.

ROTHSCHILD, W. 1904 New species of Kingfishers from Bougainville Island, Solomon Archipelago and Asuncion Island, N. Mariannes. Bull. Brit. Ornith. Club, *15*, 109, pp. 5–7.

SAFFORD, W. E. 1902 The birds of the Marianne Islands and their vernacular names. Osprey, N.S., 1.

SALVADORI, T. 1894 *Anas oustaleti*, n. sp. Bull. Brit. Ornith. Club, *4*, 20, p. 1.

SCHNEE, P. 1901 Eine auffallende Vogelzugstrasse vom nordwestlichen Nordamerika nach Polynesien. Ornith. Monatsber., *9*, pp. 131–132.

——— 1904 Die Landfauna der Marschall-Inseln nebst einigen Bemerkungen zur Fauna der Insel Nauru. Zool. Jahrb.,

Abt. Syst., *20*, 4, pp. 387–412. (pp. 389–390)

——— 1912 Einiges über die höhere Tierwelt der Marianen. Zeits. Naturwiss., *82*, pp. 458–470.

SCLATER, P. L. 1867 Bemerkungen über die Genera und Species der Cypseliden. Jour. Ornith., *15*, pp. 112–141.

SEALE, A. 1901 Report of a Mission to Guam. Bernice P. Bishop Mus., Occ. Pap., *1*, 3, pp. 17–128. (p. 27)

SHARPE, R. B. 1892 *Aphanolimnas*, n. gen. Bull. Brit. Ornith. Club, *1*, pp. 19–20.

——— 1892 Catalogue of the Birds in the British Museum. vol. VII. (p. 260) Brit. Mus. (Nat. Hist.), London.

SNOUCKAERT VAN SCHAUBURG, R. 1931 Les Zostéropides. Alauda, (2) *3*, pp. 13–27.

——— 1932 Zostéropides nouveaux. Alauda, (2) *4*, pp. 110, 459.

STRESEMANN, E. 1913 Ornithologische Miszellen aus dem Indo-Australischen Gebiet. Nov. Zool., *20*, pp. 289–293. (p. 293)

——— 1930 *Megazosterops* novum genus Zosteropidarum. Ornith. Monatsber., *38*, 5, p. 159.

——— 1931 Die Zosteropiden der Indo-Australischen Region. Ein Versuch zu ihrer natürlichen Gruppierung. Mitt. Zool. Mus. Berlin, *17*, 2, pp. 201–238.

SWAINSON, W. 1821 *Halcyon cinnamominus*. Zoological Illustration, or Original figures and Descriptions of New, Rare, or interesting animals, 1st ser., 2, pl. 67.

鷹司信輔 (TAKA-TSUKASA, N.) 1929 第六回鳥の展覽會に初めて出品せられし鳥[Birds Exhibited for the First Time at the Sixth Bird Exhibition]. かひどり [Kaidori, or Pet Birds], *2*, 2, pp. 29–37. (p. 36)

——— 1931 紅頭秧鷄と南洋大秧鷄 [Red-headed Rail [?] and *Rallina fasciata* (Raffles)]. 鳥 [Tori, or Birds], 7, 31, pp. 11–13.

——— 1932-38 The Birds of Nippon. vol. I, pts. 1–7. (Aug. 15, 1932; Nov. 10, 1938—a serial publication)

——— 1938 私の好きな飼鳥「綠鳩 [Pet Birds That I Like (Japanese Green Pigeon or *Sphenocercus s. sieboldii*)]. かひどり [Kaidori, or Pet Birds], *2*, 10, pp. 23–34. (pp. 31–32)

鷹司信輔 [TAKATSUKASA, S.] 黑田長禮 (KURODA, N.) 1915 本會採集南洋諸島產鳥類目錄 (List of Birds collected in the North Pacific Islands by the Ornithological Society of Japan). 鳥, [Tori, or Birds], *1*, 2, pp. 49-55.

——— ——— 1915 新占領南洋諸島產鳥類目錄及び分布表 (A table of Birds known at present from the various islands and island-group of western Pacific, formerly belonging to Germany but now occupied by Japan). 鳥, [Tori, or Birds], *1*, 2, pp. 60–64.

鷹司信輔 [TAKATSUKASA, S.] 山階芳麿 (YAMASHINA, Y.) 1931 パラオ及びマリアナ群島に產する數種の新しき鳥 (Some new birds [rails] from the Palao and Mariana Island). 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *43*, 513, pp. 484–487.

——— ——— 1931 カロリン群島產の二新鳥 (On two new Birds from the Caroline Islands). 動物學雜誌, [Dōbutsugaku Zasshi, or Zoological Magazine], *43*, 516, pp. 599–600.

——— ——— 1931 パラオ產カラスモドキに就いて (On *Aplornis opacaorii* subsp. nov. from the Palau Islands). 動物學雜誌[Dōbutsugaku Zasshi, or Zoological Magazine], *43*, 512, pp. 458–459.

——— ——— 1931 On two new forms of the Micronesian Birds. Tori, 7, 32, pp. 109–110.

——— ——— 1932 再び南洋の鳥に就いて(Second Report on the Birds of the South Sea). 動物學雜誌 [Dōbutsugaku

Zasshi, or Zoological Magazine], *44*, 524, pp. 221–226.

TEMMINCK, C. J. 1823 Nouveau Recuéil des Planches Coloriée d'Oiseaux, pour servier de suite a Buffon, Paris. lvr. 32, pl. 190.

TOWNSEND, C. H. & WETMORE, A. 1919 Report on the scientific results of the expedition to the tropical Pacific in charge of ALEXANDER AGASSIZ, on the U. S. Fish Commission Steamer "Albatross," from August, 1899 to March, 1900. XXI. The Birds. Bull. Mus. Comp. Zoöl., Harvard, *63*, 4, pp. 151–225.

TRISTRVM [TRISTRAM], H. B. 1883 On the Position of the Acrocephaline Genus *Tatare*, with Descriptions of Two New Species of the Genus *Acrocephalus*. Ibis, 5th ser., *1*, pp. 38–46.

内田清之助 (UCHIDA, S.) 1940 南洋の鳥類 (Birds of the South Seas) 太平洋協會編: [In: Taiheiyō Kyōkai, or Pacific Society]:南洋諸島—— 自然と資源 [Nanyō shotō shizen to shigen, or South Sea Islands—Nature and Resources], 河出書房, 東京 [Kawade Shobō, Tokyo]. pp. 147–206, (5)–(6).

WINGLESWORTH [WIGGLESWORTH], L. W. 1891 Aves Polynesiae. (A Catalogue of the Birds of the Polynesian Subregion (not including the Sandwich Islands).) Abh. Ber. Zool. Anthropo-Ethnogr. Mus. Dresden, 1890–91. no. 6. 92 pp.

——— 1892 On the Polynesian Members of the Genus *Ptilopus*. Ibis, 6th ser., *3*, pp. 566–584. (pp. 583–584)

山田信夫 [YAMADA, N.] 1939 パラオ群島の鳥 [Birds of Palau]. 野鳥 [Notori, or Field Birds], *6*, 1, pp. 55–65.

山階芳麿 (YAMASHINA, Y.) 1932 南洋採集記 [Collecting in the South Sea]. かひどり [Kaidori, or Pet Birds], *2*, 9, pp. 1–13.

——— 1932 ミクロネシアに於ける鳥類の分布に就いて [Distribution of the Birds of Micronesia]. 日本生物地理學會々報 [Nippon Seibutsu Chirigaku Kai Kaihō, or Transactions of the Zoogeographical Society of Japan], *3*, 2, pp. 139–148.

——— 1932 ミクロネシア産鳥類の卵の蒐集物に就いて (On a Collection of Birds' Eggs from Micronesia). 鳥 [Tori, or Birds], *7*, 35, pp. 393–413.

——— 1933–34 日本の鳥類と其の生態 [Birds of Japan and Their Ecology]. vol. *I*, nos. 1–3 (Jan. 10, 1933; May 20, 1933; June 10, 1934—a serial publication)

——— 1934 塚造りの話 [Story of the Palau Megapode]. 野鳥 [Notori, or Field Birds], *1*, pp. 2–5.

——— 1938 A New Genus of the Owl. Tori, *10*, 46, pp. 1–2.

——— 1940 Some Additions to the "List of the Birds of Micronesia." Tori, *10*, 50, pp. 673–679.

——— 1942 A New Subspecies of *Conopoderas luscinia* from the Mariana Islands. Bull. Biogeogr. Soc. Japan, *12*, 3, pp. 81–83.

4. 爬蟲類及兩棲類 (Reptilia & Amphibia)

淺野長雄 [ASANO, N.] 1938 パラオのオサガメ *Sphargis* (*Dermochelys*) *coniacea* L. [*Sphargis* (*Dermochelys*) *coniacea* L. of Palau]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *6*, 8, p. 1445.

阿刀田研二 [ATODA, K.] 1943 珍奇な習性を示すパラオの蛙に就て [On the Curious Habits of the Anura of Palau]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *5*, 2, pp. 184–193.

BURT, CH. E. & BURT, M. D. 1932 Herpetological Results of the Whitney South Sea Expedition. VI. Bull. Amer. Mus. Nat. Hist., *63*, 5, pp. 461–597.

畑 政雄 [HATA, M.] 1935 鰐狩の話 [Tales of Crocodile Hunting]. 南洋群島 [Nanyō Guntō, or South Sea Islands], *1*, 9, pp. 33–37.

林 一正 [HAYASHI, K.] 1935 南洋にタ

イマイの卵を捜る [On the Collecting of Eggs of Sea Turtles in the South Seas]. 科學知識 [Kagaku Chishiki, or Scientific Knowledge], *15*, 9, pp. 304–306.

堀井榮吉 [HORII, E.] 1916 新領土南洋諸島動物調査報告書 [Report on the Zoological Investigations or Survey of the South Sea Islands, the New Territory]. 南洋新占領地視察報告 [Nanyō Shinsenryōchi Shisatsu Hōkoku, or The Survey Report on the South Sea Islands, the New Territory], pp. 234–266 (pp. 238–239); 委任統治地域南洋群島調査資料 (1927) [Inin Tōchi Chiiki Nanyō Guntō Chōsa Shiryō, or Data on the Investigation of the Newly Occupied South Sea Islands (1927)], *I*, pp. 245–281. (pp. 249–250)

KISHIDA, K. (岸田久吉) 1929 A new Monitor from the island of Saipan, South Sea Islands. Lansania, *1*, 1, pp. 13–16.

LESSON, R. P. 1829–30 Voyage autour du monde, exécuté par Ordre du Roi, sur la Corvette de Sa Majeste La Coquille, pendant les années 1822, 1823, 1824 et 1825. Zoologie, t. II.

MERTENS, R. 1929 Die Rassen des Smaragdskinkes, *Dasia smaragdinum* LESSON. Zool. Anz., *84*, 9/10, pp. 209–220.

元田 茂 [MOTODA, S.] 1937 パラオの鰐 [Crocodiles of Palau]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *5*, 1, pp. 131–138.

——— 1938 パラオの鰐(續報) [Crocodiles of Palau (Supplement)]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *6*, 1, pp. 83–86.

波江元吉 [NAMIE, M.] 1916 南洋諸島産蛇の一種 [A Species of Snake from the South Sea Islands]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *28*, 334, pp. 330–332.

中島吉十郎 [NAKASHIMA, K.] 1920 パラオ島産の玳瑁 [Sea Turtles of Palau]. 水產研究誌 [Suisan Kenkyū Shi, or Fisheries Research Magazine], *15*, 6.

岡田彌一郎 (OKADA, Y.) 1915 西カロリン群島パラウに於る鼈甲養殖に就て [On the Culture of Tortoise Shell Turtles at Palau in the Western Caroline Archipelago]. 水產研究誌 [Suisan Kenkyū Shi, or Fisheries Research Magazine], *10*, 11.

——— 1938 A Catalogue of Vertebrates of Japan (日本脊椎動物目錄), iv + 412 pp. (Reptilia: pp. 97–108) Maruzen, Tokyo.

——— 1939 Studies on the Lizards of Japan. Contribution III. Scincidae. Sci. Rep. Tokyo Bunrika Daigaku, Sec. B, *4*, 73, pp. 159–214.

大島正滿 [OSHIMA, M.] 1943 西カロリン群島産爬虫類の分布を論じ併せてウエーベル線に及ぶ [Distribution of the Reptilia of the Western Caroline Archipelago with Notes on Weber's Line]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *55*, 2, pp. 63–64.

SCHNEE, P. 1902 Die Kriechthiere der Marshall-Inseln. Zool. Gart., *43*, pp. 354–362.

——— 1904 Die Landfauna der Marschall-Inseln, nebst einigen Bemerkungen zur Fauna der Insel Nauru. Zool. Jahrb., Abt. Syst., *20*, 4, pp. 387–412.

高橋敬三 [TAKAHASHI, K.] 1938 タイマイの背甲の形に就て [On the Shape of the Carapace of Sea Turtles]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *1*, 1, pp. 32–34.

山本繁藏 [YAMAMOTO, S.] 1939 群島に於ける鰐養殖の一考察 [A Study of Crocodile Breeding in the South Sea Islands]. 南洋群島 [Nanyō Guntō, or South Sea Islands], *5*, 7, pp. 56–70.

5. 魚 類 (Pisces)

阿部宗明 (ABE, T.) 1938 パラオの魚獲用植物 [On the Plants of Palao Used in Fishing]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *50*, 1, p. 44.

——— 1938 The Occurrence of Five Tropical Species of Globefishes (Tetraodontidae) in Japan. Zool. Mag. (Tokyo), *50*, 11, pp. 479–480.

——— 1938 A Note on Sazanami-fugu, *Tetraodon hispidus* LINNAEUS (Tetraodontidae, Teleostei). Zool. Mag. (Tokyo), *50*, 12, p. 533.

——— 1939 パラオのカクレウオ [*Carapus* of Palau]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *1*, 3, pp. 156–157.

——— 1939 A List of the Fishes of the Palao Islands. Palao Trop. Biol. Stat. Studies, *1*, 4, pp. 523–584.

——— 1942 Taxonomic Studies on the Puffers (*Tetraodontidae, Teleostei*) from Japan and Adjacent Regions I. Vertebral variation. Palao Trop. Biol. Stat. Studies, *2*, 3. pp. 477–496.

AHL, E. 1923 Zur Kenntnis der Knochenfisch-familie Chaetodontidae insbesondere der Unterfamilie Chaetodontinae. Arch. Naturg., Abt. A., *89*, 5, pp. 1–505.

AOYAGI, HY. (青柳兵司) 1941 The fishes of the family P[s]eudochromidae found in the waters of the Riu-kiu Islands and the Palau Islands. Annot. Zool. Jap., *20*, 1, pp. 41–54.

——— 1941 One new species of Pomacentridae, Pisces, from the Palau Islands. Zool. Mag. (Tokyo), *53*, 3, pp. 180–181.

——— 1941 南洋パラオの魚類 [Fishes of Palao]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *4*, 1, pp. 55–61; 2, pp. 149–158.

——— 1942 On a Collection of the Fishes at the Palao Islands. Palao Trop. Biol. Stat. Studies, *2*, 3; pp. 459–467.

淺野長雄 [ASANO, N.] 1936 南洋産トビハゼ*Periophthalmus* sp. の産卵習性 [On the Egg-laying Habits of *Periophthalamus* sp. of the South Seas]. 生態學研究 [Seitaigaku Kenkyū, or Ecological Review], *2*, 2, pp. 137–139.

——— 1936 南洋パラオ近海産魚類目錄 [List of the Offshore Fishes of the Islands of Palao]. 水產研究誌 [Suisan Kenkyū Shi, or Fisheries Research Magazine], *31*, 7, pp. 414–420.

——— 1939 南洋群島の鰻(豫報) [The Eels of the South Sea Islands (Preliminary Note)]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *2*, 2, pp. 98–101.

——— 1942 トキソテス *Toxotes jaculator* Pallas の食性に就て [On the Food Habits of *Toxotes jaculator* Pallas]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *10*, 8, pp. 772–775.

BEAN, B. A. 1904 A new pelican fish from the Pacific. Smiths. Misc. Coll., *45*, 3/4, pp. 254–255.

BORDIN, N. A. 1932 Scientific results of the yacht "Ara" expedition during the years 1926 to 1932, while in command of WILLIAM K. VANDERBILT. Fishes collected in 1929. Vanderbilt Mar. Mus., Bull., *1*, 2, pp. 1–64.

BOULENGER, C. A. 1895 Catalogue of the Fishes in the British Museum. 2nd edition. pp. xix + 394. Brit. Mus. (Nat. Hist.), London.

CUVIER, G. 1829 Le régne animal distribué d'aprés son organisation, pour servir de base à l'histoire naturelle des animaux et d'introduction à l'anatomie comparée. 2 ed. 1–5.

CUVIER, G. & VALANCIENNES, A. 1828–49 Histoire naturelle des Poissons. 1–22. Paris.

DUNCKER, G. & MOHR, E. 1925 Die Fische der Südsee-Expedition der Hamburgischen Wissenschaftlichen Stiftung 1908–09. I. Mitt. Zool. Mus. Hamburg, *41*, pp. 93–112.

——— ——— 1926 Die Fische der Südsee-Expedition der Hamburgischen Wissenschaftlichen Stiftung 1908–09. II. Mitt. Zool. Mus. Hamburg, *42*, pp. 126–136.

——— ——— 1929 Die Fische der Südsee-Expedition der Hamburgischen Wissenshaftlichen Stiftung 1908–09. III. Mitt. Zool. Mus. Hamburg, *44*, pp. 57–84.

ELERA, C. DE 1895 Catálogo sistemático de toda la faüna de Filipinas. 1, Vertebrados. pp. 1[?]1. (Pisces: pp. 45–621) Manila.

ENGELHARDT, R. 1912 Über einige neue Selachier-Formen. Zool. Anz., *39*, pp. 643–648.

FOWLER, H. W. 1900 Observations on fishes from the Caroline Islands. Proc. Acad. Nat. Sci. Philad., *51* (1899), pp. 482–496.

——— 1901 Fishes from Caroline Islands. Proc. Acad. Nat. Sci. Philad., *53*, (1900), pp. 324–326.

——— 1925 Fishes of Guam, Hawaii, Samoa and Tahiti. Bernice P. Bishop Mus., Bull., *22*, pp. 1–38.

——— 1928 The Fishes of Oceania. Mem., Bernice P. Bishop Mus. *10*, pp. 1–540.

——— 1931 The Fishes of Oceania—— Supplement I. Mem. [Bernice P. Bishop Mus.] *11*, 5, pp. 313–381.

——— 1931 The Fishes of the Families Pseudochromidae, Lobotidae, Pempheridae, Priacanthidae, Lutjanidae, Pomadasyidae and Teraponidae collected by the United States Bureau of Fisheries Steamer "Albatross," chiefly in Philippine Seas and Adjacent Waters. U.S. Nat. Mus., Bull. *100* (11), pp. 1–388.

——— 1933 The Fishes of the Families Banjosidae, Lethrinidae, Sparidae, Girellidae, Kyphosidae, Oplegnathidae, Gerridae, Mullidae, Emmelichthyidae, Sciaenidae, Sillaginidae, Apripidae, and Enoplosidae collected by the United States Bureau of Fisheries Steamer "Albatross," chiefly in Philippine Seas and Adjacent Waters. U.S. Nat. Mus., Bull. *100* (12), pp. 1–465.

——— 1934 The Fishes of Oceania—— Supplement 2. Mem. Bernice P. Bishop Mus., *11*, 6, pp. 383–466.

——— 1934 Descriptions of new fishes obtained 1907 to 1910, chiefly in the Philippine Islands and adjacent seas. Proc. Acad. Nat. Sci. Philad., *85*, (1933), pp. 233–367.

——— 1941 The Fishes of the Groups Elasmobranchii, Holocephali, Isospondyli, and Ostarophysi obtained by the United States Bureau of Fisheries Steamer "Albatross" in 1907 to 1910, chiefly in the Philippine Islands and adjacent Seas. U.S. Nat. Mus., Bull. *100* (13), pp. 1–879.

FOWLER, H. W. & BALL, S. C. 1925 Fishes of Hawaii, Johnstone Island, and Wake Island. Bernice P. Bishop Mus., Bull., *26*, pp. 1–31.

FOWLER, H. W. & BEAN, B. A. 1928 The Fishes of the Families Pomacentridae, Labridae, and Calliodontidae, collected by the United States Bureau of Fisheries Steamer "Albatross," chiefly in Philippine Seas and Adjacent Waters. U.S. Nat. Mus., Bull. *100* (7), pp. 1–525

——— ——— 1929 The Fishes of the Series Capriformes, Ephippiformes, and Squamipennes, collected by the United States Bureau of Fisheries Steamer "Albatross," chiefly in Philippine Seas and Adjacent Waters. U.S. Nat. Mus., Bull. *100* (8), pp. 1–352.

GUDGER, E. W. 1930 Helmets from skins of the porcupine fish (*Diodon hystrix*). Sci. Monthly, *30*, pp. 432–442.

GÜNTHER, A. 1859–70 Catalogue of the Fishes in the British Museum. *1–8*. Brit. Mus. (Nat. Hist.), London.

——— 1873 ANDREW GARRETT's Fische der Südsee. I. Jour. Mus. Godeffr., *2*, 3, pp. 1–24.

——— 1874 ANDREW GARRETT's Fische der Südsee. II. & III. Jour. Mus. Godeffr., *2*, 5 & 7, pp. 25–96.

——— 1875 ANDREW GARRETT's Fische der Südsee. IV. Jour. Mus. Godeffr., 2, 9, pp. 97–128.

——— 1876 ANDREW GARRETT's Fische

der Südsee. V. Jour. Mus. Godeffr., *4*, 10, pp. 129–168.

—— 1877 ANDREW GARRETT'S Fische der Südsee. VI. Jour. Mus. Godeffr., *4*, 11, pp. 169–216.

—— 1881 ANDREW GARRETT'S Fische der Südsee. VII. Jour. Mus. Godeffr., *4*, 15, pp. 217–256.

—— 1909 ANDREW GARRETT'S Fische der Südsee. VIII. Jour. Mus. Godeffr., *6*, 16, pp. 261–388.

—— 1910 ANDREW GARRETT'S Fische der Südsee. IX. Jour. Mus. Godeffr., *6*, 17, pp. 389–519.

羽根田彌太 (HANEDA, Y.) 1938 南洋の發光魚に就て [On Luminescent Fish of the South Seas]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *1*, 2, pp. 21–27.

—— 1939 魚類の發光器の一新型 [A New Luminescent Structure in Fish]. 冷光 [Reikō], *1*, pp. 48–55.

—— 1939 南洋の發光魚 [Luminescent Fish of the South Seas]. 動物學雜誌 [Dōbutsugaku Zasshi, or Zoological Magazine], *51*, 2, p. 105.

—— 1939 生物の發光 [Luminescence of Animals]. 科學 [Kagaku, or Science], *9*, 7, pp. 253–259.

—— 1940 On the Luminescencs [Luminescence] of the Fishes belonging to the Family Leiognathidae of the Tropical Pacific. Palao Trop. Biol. Stat. Studies, *2*, 1, pp. 29–39.

—— 1941 ポナペのシャギシャギ [Shagi-shagi of Ponape]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *3*, 3, pp. 181–183.

—— 1942 南海の發光生物 [Luminescent Animals of the South Seas]. 科學畫報 [Kagaku Gahō, or Illustrated Science], *31*, 1, pp. 103–108.

HERRE, A. W. 1934 The Fishes of the HERRE Philippine Expedition. Hongkong.

—— 1935 A Check list of the Fishes of the Pelew Islands. Jour. Pan-Pacific Res. Inst., *10*, 2, pp. 163–166.

—— 1936 Fishes in the Zoölogical Museum of Stanford University, III. New Genera and Species of Gobies and Blennies and a New *Myxus*, from the Pelew Islands and Celebes. Philip. Jour. Sci., *59*, 2, pp. 275–286.

—— 1939 On a collection of fishes from Nanyo, the Japanese Mandated Islands. Annot. Zool. Jap., *18*, 4, pp. 298–307. (Res. Prof. ESAKI's Micronesia Expedition. No. 37)

檜山義夫 [HIYAMA, Y.] 1942 南洋魚類雜記 [Miscellaneous Notes on South Sea Fishes]. 科學畫報 [Kagaku Gahō, or Illustrated Science], *31*, 3, pp. 44–49.

—— 1942–43 南洋産の主要魚類 [Important Fish of the South Seas]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *10* (1942), 4, pp. 396–404; 5, pp. 507–512; 6, pp. 598–602; 7, pp. 689–696; 8, pp. 788–792; 9, pp. 873–877; 10, pp. 1057–1063; 12, pp. 1143–1148; *11* (1943), 1, pp. 88–92; 2, pp. 189–193; 3, pp. 275–281; 4, pp. 365–368; 5, pp. 441–444; 6, pp. 525–529; 7, pp. 597–601; 8, pp. 679–683.

—— 1943 南洋有毒魚類調査報告 [Report on Investigations of Poisonous Fish of the South Seas]. 137, pp., 29 pls. 日產水產研究所小田原支所, 小田原 [Nissan Fishery Research Station, Odawara Branch, Odawara].

HOMBRON, J. B. & JACQUINOT, C. H. 1853 Voyage au Pole Sud et dans l'Océanie, sur les Corvette l'Astrolabe et la Zélée, exécuté par Ordre du Roi, pendant les années 1837–1840. Zoologie, t. III, pt. 2. (pp. 29–56)

堀井榮吉 [HORII, E.] 1916 新領土南洋諸島動物調査報告書 [Report on the Zoological Investigations or Survey of the South Sea Islands, the New Territory] 南洋新占領地視察報告 [Nanyō Shinsenryō-chi Shisatsu Hōkoku, or the Survey Re-

port on the South Sea Islands, the New Territory], pp. 234–266 (pp. 239–240); 委任統治地域南洋群島調査資料 (1927) [Inin Tōchi Chiiki Nanyō Guntō Chōsa Shiryō, or Data on the Investigation of the Newly Occupied South Sea Islands (1927)], *I*, pp. 245–281 (pp. 250–251).

JORDAN, D. S. & SEALE, A. 1906 The Fishes of Samoa, description of the species found in the archipelago, with a provisional check-list of the fishes of Oceania. Bull. Bur. Fish., *25*, (1905), pp. 175–455, pls. 33–53.

蒲原稔治 [GAMAHARA, T.] 1940 堅皮類 [Sclerodermi]. 日本動物分類 [Nippon Dōbutsu Bunrui, or Fauna Nipponica], XV, *2*, 3, pp. 1–112.

——— 1940 的鯛族 [Zeoidei]. 破鰭族 [Rhegnopteri]. 溝背族 [Holconoti]. 日本動物分類 [Nippon Dōbutsu Bunrui, or Fauna Nipponica], XV, *2*, 4, pp. 1–80.

——— 1940 鱸型族 [Percomorphi]. 鯖群(鰺型類ヲ除ク) [Mackerel Group (excluding Horse-mackerels)]. 日本動物分類 [Nippon Dōbutsu Bunrui, or Fauna Nipponica], XV, *2*, 5, pp. 1–225.

加藤源治 [KATO, G.] 1940 パラオと各地間の魚類輸送 [Transportation of Fishes from Palao]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *3*, 2, pp. 117–122.

KAUP, J. J. 1856 Catalogue of apodal fish in the collection of the British Museum. viii + 163 pp., 19 pls. Brit. Mus. (Nat. Hist.), London.

KENDALL, W. C. & GOLDSBOROUGH, E. L. 1911 Reports on the scientific results of the expedition to the tropical Pacific, in charge of ALEXANDER AGASSIZ, by the U.S. Fish Commission Steamer "Albatross," from August, 1899 to March, 1900. The shore fishes. Mem. Mus. Comp. Zoöl., Harvard, *26*, 7, pp. 241–344.

KITTLITZ, F. H. VON 1834 Beschreibung mehrer neuer oder wenig gekannter Arten des Geschlechtes *Acanthurus*, im Stillen Ocean, beobachtet und nach dem Leben abgebildet. Mus. Senckenbergianum, *1*, pp. 189–196.

——— 1858 Denkwürdigkeiten einer Reise nach dem russischen Amerika, nach Mikronesien und durch Kamtschatka. 2 vols. Gotha.

KNER, R. 1868 Ueber neue Fische aus dem Museum der Herrn JOHANN CASER GODEFFROY und Sohn in Hamburg. Sitzber. Akad. Wiss. Wien, *58*, 1, pp. 293–356.

LESSON, R. P. 1828 Description du nouveau genre *Ichthyophis* et de plusiers espéces inedites ou peu connues de poissons, recueillis dans le voyage autour du monde de "La Coquille." Mem. Soc. Hist. Nat. Paris, *4*, pp. 397–412.

——— 1830 Voyage autour du monde, exécuté par Ordre du Roi, sur la Corvette de Sa Majesté, La Coquille, pendant les années 1822, 1823, 1824 et 1825. Zoologie t. II, pt. 1. (pp. 66–238)

丸川久俊 [MARUKAWA, H.] 1939 南洋群島の水産(八) [Fisheries of the South Sea Islands, 8]. 南洋水産 [Nanyō Suisan, or South Sea Fisheries], *5*, 9, pp. 10–38.

——— 1940 海洋學上より觀たる南洋群島の水産 [Fisheries of the South Sea Islands from the Standpoint of Oceanography]. (南洋水産叢書, 8) [Nanyō Suisan Sōsho, or South Sea Fisheries Symposium, 8] 134 pp. (pp. 74–101) 南洋水産協會 [Nanyō Suisan Kyōkai, or South Sea Fisheries Association, publisher].

松井喜三 [MATSUI, K.] 1942 鰹, 鮪の腦の成長並にその水分量, 脂肪量に就いて [Growth, Water and Fat Content of the Brain of Tuna]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *5*, 1, pp. 106–116.

——— 1942 パラオ近海産鰹の生殖巢に就いて [Breeding Areas of Tuna in the Vicinity of the Palau Islands]. 科學南洋

[Kagaku Nanyō, or South Sea Science], *5*, 1, pp. 117–122.

松尾陸一 [MATSUO, R.] 1934 「ヤルート」島ニ於ケル毒魚ノ調査研究 [Investigations on the Poisonous Fishes of Jaluit Island] 南洋醫學論文集 [Nanyō Igaku Ronbunshu, or Collection of Medical Publications on the South Seas], *2*, pp. 309–326, pls. 37–46.

MOHR, E. 1926 Die Gattung *Zeanrchopterus* GILL. Zool. Jahrb., Abt. Syst., *52*, pp. 231–266.

MONTILLA, J. R. 1938 A Review of Philippine Holocentridae. Philip. Jour. Sci., *67*, 2, pp. 207–229.

日産水産研究所 [Nissan Fisheries Research Station] 1941 南洋食用水族圖說 (Illustrated Atlas of Edible Marine Animals and Plants of the South Seas]. 149 pls. (pls. 1–130)

——— 1943 南洋有毒魚類調査報告 [Report on the Investigations of Poisonous Fish of the South Seas]. 檜山 1943 を見よ [see Hiyama, 1943].

尾形藤治 [OGATA, T.] 1942 南洋紀行 (九) [An Account of a Journey through the South Sea Islands (9)]. 水玉魚[?]. 町田報德 [Machida, Hōtoku], 90, pp. 4–5.

OGILBY, J. D. 1915 Ichthyological notes. No. 1. Mem. Queensland Mus., *2*, pp. 90–93.

OKADA, Y. (岡田彌一郎) 1938 A Catalogue of Vertebrates of Japan (日本脊椎動物目錄). iv + 412 pp. (Pisces: pp. 114–275) Marzen, Tokyo.

岡田彌一郎[OKADA, Y.] 松原喜代松 (MATSUBARA, K.) 1938 日本産魚類檢索 (Keys to the fishes and fish-like animals of Japan). XL + 584 pp. 三省堂, 東京 [Sanseidō, Tokyo, publisher].

岡島 清 [OKAJIMA, K.] 1936 鮫の話 [A Shark Story]. 南洋群島 [Nanyō Guntō, or South Sea Islands], *2*, 2, pp. 41–49.

PELLEGRIN, J. 1898 Contribution à l'étude ichthyologique des iles Mariannes, d'aprés les envois de M. MARCHE. Bull. Mus. Hist. Nat. Paris, *4*, pp. 228–229.

PIETSCHMANN, V. 1930 Remarks on Pacific fishes. Bernice P. Bishop Mus., Bull. *73*, pp. 1–24.

PÖHL, [?] 1884 Museum Godeffroy, Catalogue 9 & 10.

QUOY, J. R. C. & GAIMARD, J. O. 1824 Voyage autour du monde, entrepris par Ordre du Roi, exécuté sur les Corvettes de S.M. l'Uranie et la Physicienne, pendant les années 1817, 1818, 1919 [1819] et 1820. Zoologie. (poisson: pp. 183–401)

SAUVAGE, H. E. 1879 Description de quelques poissons d'espéces nouvelles de la collection du Muséum d'Histoire Naturelle. Bull. Soc. Philom. Paris, 7, 3, pp. 204–209.

SCHMELTZ, J. D. E. 1864–81 Museum Godeffroy, Catalogue 1 (1864); Catalogue 2 (1865); Catalogue 3 (1866); Catalogue 4 (1869); Catalogue 5 (1874); Catalogue 6 (1877); Catalogue 7 (1879); Catalogue 8 (1881).

SEALE, A. 1901 Report on a Mission to Guam, pt. 2, Fishes. Bernice P. Bishop Mus., Occ. Papers, *1*, 3, pp. 61–128.

高垣忠彦 [TAKAGAKI, T.] 杵淵 博 [KINEFUCHI, H.] 傳亮 [DEN, T.]. 1941 パラオ諸島魚類採集報告 [Reports on the Collecting of Fishes in the Palau Archipelago]. 博物學雜誌 [Hakubutsu Gaku Zasshi, or Natural History Magazine], *38*, 72, pp. 3–14.

高橋敬三 [TAKAHASHI, K.] 1941 パラオのタマカイ [? of Palau]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *4*, 2, pp. 161–162.

TOMIYAMA, I. (富山一郎) 1936 Gobiidae of Japan. Jap. Jour. Zool., *7*, 1, pp. 37–112.

VAILLANT, L. 1893 Sur un nouveau genre de poissons, voisin des Fierasfer. C. R Acad. Sci. Paris, *117*, pp. 745–746.

WAITE, E. R. 1903 Notes on Zoology of Paanopa or Ocean Island and Naura or Pleasant Island, Gilbert Group; The Fishes. Rec. Austr. Mus., *5*, 1, pp. 2–3.

WEBER, M. & BEAUFORT, L. F. DE 1916 The Fishes of the Indo-Australian Archipelago. vol. 3, Ostariophysi: II, Cyprinoidea, Apodes, Synbranchii. 455 pp., 214 figs.

安川 隆 [YASUKAWA, T.] 1934 南洋毒魚調査報告 [Reports on the Investigations of Poisonous Fishes of the South Sea]. [謄寫刷] [Mimeographed]. 南洋廳 [Nanyōchō, or Government of the South Sea Islands].

——— 1941 鰹鮪の産卵地調査に關する座談會 [Record of the Conference on the Investigation on Breeding Areas of the Tuna]. 科學南洋 [Kagaku Nanyō, or South Sea Science], *4*, 1, pp. 64–75.

6. 原索動物 (Protochordata)

DRASCHE, R. von 1882 *Oxycorynia*, eine neue Synascidien-Gattuns. Verh. Zool.-bot. Ges. Wien, *32*, pp. 175–178.

ESCHSCHOLTZ, FR. 1825 Bericht über die zoologische Ausbeute der Reise von Kronstadt bis St. Peter und St. Paul. OKEN'S Isis, (1825), pp. 734–747.

HELLER, C. 1878 Beiträge zur nähern Kenntniss der Tunicaten. Sitzber. Akad. Wiss. Wien, Abt. *I*, Jänner-Heft, Jahrb. 1878, *77*, pp. 1–28.

MICHAELSEN, W. 1905 Revision von HELLER'S Ascidien-Typen aus dem Museum Godeffroy. Zool. Jahrb., Suppl., *8*, 1, pp. 71–120.

OKUDA, S. (奥田四郎) 1639 [sic] The Enteropneusta from the Palau Islands. Jour. Fac. Sci. Hokkaido Imp. Univ., Ser. VI, Zool., *7*, 1, pp. 17–25.

——— 1939 邦産既知ギボシムシに就いて [On Already Known Japanese Hemichordates]. 植物及動物 [Shokubutsu oyobi Dōbutsu, or Botany and Zoology], *7*, 10, pp. 1771–1772.

STIASNY, G. 1920 Ueber westindische Tornarien nebst einer Uebersicht über die bisher bekannten tentaculaten Tornarien. Versl. Kon. Akad. Wetenshap., *29*, pp. 1–35.

——— 1934 Über einige exotische Tornarien. Verh. Kon. Akad. Wet. Amsterdam Afdeel. Naturkd. (Tweede Sectie), *34*, 2, pp. 1–27.

STIASNY-WIJNHOFF, G. & STIASNY, G. 1927 Die Tornarien. Kritik der Beschreibungen und Vergleich sämtlicher bekannter Enteropneustenlarven. Ergebn. Fortschritte Zool., *7*, pp. 38–208, charts 1–7.

TOKIOKA, T. (時岡 隆) 1942 Ascidians Found on the Mangrove Trees in Iwayama Bay, Palao. Palao Trop. Biol. Stat. Studies, *2*, 3, pp. 497–506.

——— 1942 Systematic Studies of the Plankton Organisms Occurring in Iwayama Bay, Palao. VII. A Preliminary Report on the Appendicularian Fauna of the Bay and the Adjacent Waters. Palao Trop. Biol. Stat. Studies, *2*, 3, pp. 613–616.

Arsenic Toxicity Studies in Soil and in Culture Solution[1]

HARRY F. CLEMENTS and JEROME MUNSON[2]

THE PROBLEM OF arsenic accumulation in soils is one of comparatively recent importance. As agriculture became more intensive, it became necessary to use poisons to combat attacks of certain insects, fungi, and more recently, weeds. Because arsenic is very poisonous to plant enemies and because it is comparatively cheap, it was only natural that it should have found general use. The arsenic so used has for the most part accumulated in the upper soil layers, and sooner or later becomes a menace to crop production. This paper is concerned with this problem particularly with reference to Hawaiian soils.

HISTORICAL REVIEW

Early work.—Toward the end of the last century and the beginning of the present century, some attention was given to the possibility that arsenic might poison the crop itself. In 1894, Lyttkens conducted experiments at the Halmstead Experiment Station in Sweden which showed plainly that the arsenic in the soil is a strong poison to plants.

Stoklasa (1898), however, showed that while arsenic could not replace phosphorus as an essential element, it had stimulative effects on the development of the assimilation organs of the oat plant. The issue thus became confused. While some presented evidence that arsenic was a poison to plants, others presented equally convincing evidence that arsenic stimulated plant growth. Bouilhac (1899) reported that a number of fresh-water algae absorb arsenic acid from arsenates without apparent injury, and the growth of one appeared more favorably influenced by arsenic acid than by phosphoric acid.

The fact that arsenic is a natural component of most soils and not uncommon in plants tended to reduce the force of criticism against the use of it. Zuccari (1914), working in Italy, analyzed 20 soil samples varying in physical and chemical composition and taken from different depths in different geological formations and at varying elevations; these samples showed an arsenic content varying from 0.187 to 6 parts per 100,000 of soil, being largest in soils containing the most iron compounds and varying almost directly with iron content.

Reichert and Trelles (1922) analyzed 20 soils from different parts of Argentina and found all but one to contain arsenic, varying in amounts from 0.1 to 2.25 mg. per 100 gm. of soil.

Williams and Whetstone (1940) analyzed a wide range of soils for arsenic and found the range of naturally occurring arsenic to be between 0.3 and 40 ppm. Vegetation found growing on these soils ranged from less than 0.1 ppm to 10 ppm.

Greaves (1934) analyzed, for total arsenic, water-soluble arsenic, and various soluble salts, 50 orchard soils which had been in cultivation for some time and which varied widely in chemical, physical, and biological properties. Total arsenic varied from 7.2 to 367.2 pounds per acre foot. The water-soluble arsenic varied from 0.7 to 31.9 pounds per acre foot.

Greaves (1913*a*) earlier reported that some virgin soils contain arsenic in appreciable quantities which comes from the decay of native rocks. Many cultivated orchard soils contain it in large quantities, but he found no uniform relationship between the total quantity in different soils and the water-soluble arsenic of these soils. He considered that the solubility of arsenic is governed largely by the salts in the soil and the form in which the arsenic is applied.

Thus, with comparatively high arsenic amounts not uncommon as natural components of soils, opinions on the danger from the use of comparatively small additions continued to be diverse.

Headden (1909) was perhaps the first to recognize the serious dangers which may accrue to orchard trees from continued use of arsenical insecticides. In fact, he set off a heated controversy which has raged ever since. In other reports (1908; 1910), he recognized three types of poison-

[1] Published with the approval of the Director of the University of Hawaii Agricultural Experiment Station as Technical Paper 156. Manuscript received February 15, 1947.

[2] Dr. Clements is Professor of Botany and Plant Physiologist, University of Hawaii Agricultural Experiment Station. Mr. Munson was formerly a graduate assistant in botany, University of Hawaii; his master's thesis, now in the University Library, is incorporated in the present paper.

ing, one corrosive, one systemic, and one which was an arsenic-lime poisoning. He pointed out that arsenical deposits in the soil are for the most part insoluble, but warned that the soluble fractions had already passed the danger limits in certain areas. He recognized that absorption of arsenic by the roots takes place. He further pointed out that salts such as NaCl, Na_2SO_4, and Na_2CO_3 are all capable of making lead arsenate soluble in the soil solution and that lime salts do not prevent the solution of arsenates.

Headden was joined in his efforts by Swingle and Morris (1911), who reported that serious injury may result to apple trees from the application of insoluble arsenicals and that recent wounds through the outer bark, functional lenticels, and dormant buds permit the absorption of arsenic in solution.

Greaves (1913) observed that water-soluble arsenic may exist in soils to the extent of 82 ppm without entirely stopping ammonification and nitrification. He considered it improbable that lead arsenate, zinc arsenite, or arsenic trisulfide would ever be applied to agricultural soil in quantities sufficient to be injurious to soil bacteria.

Greaves and Anderson (1915) reported actual stimulation of soil flora by soluble arsenic in soil at 10 ppm. Toxicity began at 40 ppm and nitrogen fixation was entirely stopped at 250 ppm. The quantity of 10 ppm which they reported as causing stimulation exceeds that found in most soils, and they concluded that arsenic will stimulate instead of retard bacterial activities of soil. Greaves (1916) reported that arsenic cannot replace phosphorus in the vital process of nitrogen fixing, but it can, in some manner, liberate phosphorus from its insoluble compounds.

Swingle (1920) investigated the effect of arsenic on species of soil bacteria responsible for important chemical changes such as ammonification and nitrogen fixation. Contrary to the work of Greaves, Swingle's results showed that all the arsenical compounds used were germicidal, but in different degrees.

Green and Kestell (1919) found bacteria which are resistant to arsenic to be infrequent in soil and air, but fairly frequent in feces. Of the twelve or more resistant species examined, only two showed any chemical activity toward arsenic: one, which oxidizes arsenite to arsenate, and another, which reduces arsenate to arsenite. No relationship was discovered between arsenate reduction and nitrate reduction.

McGeorge (1915*a*; 1915*b*) appears to have been the first in Hawaii to recognize the possible deleterious effects which may result from the use of sodium arsenite as a herbicide, a practice then coming into general use in the Territory. His researches involved a study of the effect of sodium arsenite on the growth of millet, cowpeas, and buckwheat and on the physical, chemical, and biological activities in heavy red clay, brown clay, and highly organic silt soils. He found that the effect of sodium arsenite on plant growth depends upon the resisting power of the plant and upon the chemical and physical nature of the soil. In small quantities, the compound stimulated plant growth in most instances, but when added at the rate of 0.1 to 0.25 per cent, it made plant growth virtually impossible.

Sodium arsenite, he discovered, materially altered the mechanical condition of the soil, its action being primarily that of a deflocculating agent checking the movement of water.

Sodium arsenite, McGeorge showed, was strongly fixed by the soil, even resisting the washing of heavy rains. An analysis of a sample of soil from a tract of land sprayed three times a year for 5 years, at the rate of 5 pounds of sodium arsenite per acre per application, showed all the arsenic to be present in the top 4 inches of soil. The fixation of arsenites by the soil involved chemical reactions consisting of replacement of solution of iron, calcium, magnesium, and humus, owing in part to a hydrolysis of the sodium arsenite in solution and in part to a combination with the dibasic and tribasic elements, to form the relatively insoluble arsenites and arsenates.

Brenchley (1914*a*; 1914*b*) distinguished between higher and lower forms of plant life in their reactions to arsenic. In certain algae, stimulation may result from the presence of arsenic compounds. Some fungi apparently are able to live in the presence of arsenical compounds. On higher plants, the toxic effect of arsenic was found much more marked with arsenious acid and its compounds than with arsenic acid and its derivatives. Using peas and barley, she could observe no stimulation even with the smallest quantities used.

Morris and Swingle (1927) reported that the addition of small amounts of soluble arsenical compounds to potted plants caused serious injury to most of the plants under test. The authors concluded that the incorporation of arsenical compounds in the soil is a dangerous practice, and may cause considerable injury as the concentration increases. They further concluded that beans and cucumbers were very susceptible, whereas cereals and grasses were more resistant.

To judge from the material so far presented, it appears that the use of arsenic has several problems associated with it. The preponderance of opinion is that arsenic is harmful to higher plants but that when the arsenic occurs in very small concentrations, it may cause some stimulation. Contrary opinion on the latter point is, however, rather substantial. The stimulating effect of arsenic on algae and fungi seems not uncommon, but its favorable influence on soil organisms regarded as useful to agriculture is at least questionable. While the argument was going along on these somewhat academic lines, great quantities of arsenic were

applied to orchards and fields. As Headden and Swingle had warned, the continued application and the resulting accumulations of arsenic in the surface layers of soil and its retention there resulted in crop reduction or failure in Washington as reported by Vandecaveye, Horner, and Keaton (1936), in South Carolina as reported by Albert and Paden (1931) and Cooper *et al.* (1931), and in Louisiana as reported by Reed and Sturgis (1936). During the past 15 years, experimental work on arsenic has been directed to several problems: the contamination of plant parts which are used as animal or human food, the levels at which arsenic in soil may cause a reduction in crop yields, and methods which might be used to render a poisonous soil suitable for renewed crop production.

Recent work: Arsenic in food.—Chorley and McChlery (1935), interested in the poisoning of fowls following their consumption of poisoned locusts, reported that when arsenic is administered in small quantities such as occur on sprayed grasshoppers, a domestic fowl can tolerate comparatively large doses over a long period without any visible ill effects.

Franke and Maxon (1936) gave rats intraperitoneal injections of disodium acid arsenite and disodium acid arsenate, as well as other chemicals. The minimum fatal doses were defined as the smallest doses which would kill 75 per cent or more of the animals in less than 2 days. The minimum fatal doses of the arsenite were 4.25–4.75 mg. of arsenic per kilogram of weight, whereas for the arsenate, the fatal dose was 14–18 mg. per kilogram.

Groves, McCulloch, and St. John (1946) concluded from their studies that lead arsenate spray residues are much less toxic to swine than has generally been supposed. One pig consumed the spray residue from 1,007 kilograms (over 1 ton) of heavily sprayed apples which contained 114.8 gm. of lead arsenate in the form of spray residue. The pig gained in weight approximately as much as the control pig, and no abnormalities were apparent in blood studies on it. Data showed that of the edible portions of the pigs which were fed large quantities of lead arsenate, only the livers contained more lead than the 7.14 ppm legal limit, and none of the organs analyzed contained more than the limit of 3.57 ppm of As_2O_3.

The effect which spray residues on plant parts and metabolized arsenic contained within plant tissue may have on higher animals, including humans, has been receiving increasing attention. Talbert and Tayloe (1933), reporting results of feeding spray chemicals to rats, concluded that if it may be assumed that the spray chemicals have an effect upon man similar to that which they have on albino rats, it is their opinion that there is little likelihood that a human being would consume as spray residue on apples, sprayed and handled in the usual manner, enough arsenic either at one time or over an extended period to be injurious.

Coulson, Remington, and Lynch (1934) compared the bodies of rats fed for 3 to 5½ months on diets of varying arsenic content derived (1) from natural shrimp and (2) from added arsenic trioxide. The bodies of animals which had received the largest amount of arsenic, 17.9 mg. per kilogram, in the form of shrimp contained at least four times as much arsenic as the stock diet controls, whereas those which received approximately the same quantity of arsenic in the form of arsenic trioxide contained 55 to 65 times as much as the controls. An even greater difference between the storage of arsenic from the two forms was shown during the first 3 months than after 5½ months, a fact suggesting that the rats receiving the inorganic arsenic had at some period during the first 3 months reached an equilibrium, after which no further storage took place.

There was no retardation of growth in any of the arsenic fed animals nor any observable differences in their physical vigor or appearance, and in none of them was there any histological evidence of injury to the spleen, liver, or kidney due to the feeding of arsenic at the level employed.

These authors (1935) further emphasized the difference between metabolized and inorganic arsenic in foods by showing that arsenic as present in shrimp was found to be far less available for storage in young rats than when fed at the same level as As_2O_3. During the first 3 months of their feeding trial, 18 per cent of the As_2O_3 incorporated in the diet at a level of 17.9 mg. per kg. was stored as against 0.77 per cent for the same amount of arsenic in shrimp. The total amount stored was not significantly increased by feeding the element for an added 9 months. There was no evidence of toxicity from the arsenic in either form after 12 months of feeding.

In two human subjects studied by these authors, the ingestion of shrimp in amounts furnishing 1,180 and 980 gammas of arsenic was followed by rapid and complete elimination of the arsenic. Inorganic arsenic, although excreted more slowly than shrimp arsenic, was apparently eliminated more completely by these subjects than by the rats. These results are considered to be of interest not only for the light which they throw on the metabolism of arsenic, but also as additional evidence that the manner in which inorganic elements are used in the body depends upon the source or form in which these elements are presented.

It appears, therefore, that arsenic which has been metabolized by an organism—that is, arsenic which the organism has absorbed and made a part of itself—is less dangerous to animals than is inorganic arsenic such as may appear on the leaves of plants shortly after spraying. This latter arsenic is quite poisonous to livestock, as most sections of

an agricultural country recognize. In an effort to determine how much arsenic plants might absorb and remain normal in appearance, Machlis (1941) grew bush beans and Sudan grass in culture solution. He presented striking evidence that the bean plant may absorb arsenic far in excess of legal tolerance and yet show no reduction in growth.

To discover the factors which may or may not make the use of arsenic-contaminated food safe for animal or human consumption requires further critical studies. On the basis of recent work it appears, however, that there has been more emotion and less knowledge about this subject than is needed for an understanding of it.

Recent work: Arsenic accumulation in soil, its effect on crop production, and corrective measures.—Swingle (1923), in an effort to test the effect of prolonged application of arsenic on plant growth, applied various arsenicals to plots of ground in the spring of the year, and the effect on crop production was noted. After 7 years of such procedure, beans and cucumbers made little growth, while wheat and timothy grew fairly well. No further applications of arsenic were made for 6 years and at the end of that time it was found that very little of the arsenical had been removed by rains or irrigation. Furthermore, it was found very difficult to get the land back into condition for cropping.

Paden and Albert (1930), working in South Carolina, reported a relationship between the unproductivity of certain soil types and the accumulation of soluble arsenic in the soil resulting from heavy applications of calcium arsenate. Lime improved the growth of cotton in the poisoned soil. Soils which were relatively low in iron and other materials which would be expected to render arsenic insoluble were found to be the most seriously affected by the arsenates.

Albert and Arndt (1931) found the concentration of soluble arsenic as measured by collodion bag dialyzates to be a more reliable index of arsenic than is the total arsenic present in the soil. In greenhouse experiments, the addition of 1 ppm of arsenic definitely retarded root and top growth of cowpeas. It was observed that the concentration of 1 ppm of soluble arsenic as measured by the collodion bag test was not unusual in soil which had been receiving doses of arsenates. Liming and the use of fertilizer along with iron and clay compounds of the soil played an important role in rendering arsenates harmless to sensitive crops.

Hurd-Karrer (1936) believed as a result of field tests and culture solutions that phosphate application will reduce or prevent arsenic injury to plants where the soil type is such as to retain the phosphate in available form.

Heggeness (1940), growing tomatoes in culture solution, found no evidence of toxic stimulation, even the most dilute solution (½ ppm) reducing the yield by 20 per cent. Arsenic toxicity in the tomato was partially dependent on phosphate availability.

Keaton (1938) studied the oxidation-reduction potentials of arsenate–arsenite systems in sand and soil mediums. In these soils arsenic was fixed by absorption and combination, but it was observed that a higher percentage of arsenate than arsenite was fixed by these soils. The addition of iron to the system when the original ratio of arsenate to arsenite was unity increased the redox potential independent of the medium used. In the two soils studied the colloidal fraction possessed a greater reducing capacity and a lower potential than the soil from which it was extracted.

Keaton and Kardos (1940) attempted treatment of orchard soil to overcome toxicity of arsenic residues. Their studies indicate a relationship between the oxidation-reduction potentials of the soils treated and the conditions of plant growth. The addition of ferric oxide caused an increase in the redox potential. Alumina produced no effect in oxidation or reduction. Soils with a high colloid content were characterized by low potential and small percentage oxidation. They suggested that poisoned soils be treated with some mild oxidizing agent capable of arsenic fixation, and named iron oxide as such an agent.

Kardos, Vandecaveye, and Benson (1940) reported that severely toxic soils have been rendered productive by making applications of 3 to 4½ tons of *ferrous* sulfate per acre.

EXPERIMENTAL WORK

In order to study certain phases of arsenic toxicity, the experiments reported in this paper were undertaken. Data will be presented and discussed under the following headings:

Part I. The comparative toxicity of trivalent and pentavalent arsenic on bean (*Phaseolus vulgaris* L.), Sudan grass (*Sorghum vulgare* Persoon var. *sudanense* [Piper] Hitch.), and tomato (*Lycopersicon esculentum* Miller).

Part II. The effect of different phosphorus levels on the toxicity of trivalent and pentavalent arsenic on bean, Sudan grass, and tomato.

Part III. The influence of repeated croppings of bean, Sudan grass, and tomato on a red residual soil and

on a black alluvial soil treated with various increments of arsenic.

MATERIALS AND METHODS

Culture solutions.—For Part I and Part II mentioned above, water cultures were used. A total of 30 crocks was used for each of the three species—10 crocks at each of three phosphorus levels—with each crock having a known concentration of arsenic in the form of sodium arsenite in the study of the trivalent form and sodium arsenate in the study of the pentavalent form.

The experiments were conducted in a greenhouse of the University of Hawaii Agricultural Experiment Station. Four-gallon size glazed crocks were used for the Sudan grass and tomato samples, and 2-gallon size for the bean. Distilled water was used throughout and continuous aeration maintained. The plants were held in corks set into lids which fitted over the crocks.

The tomato and Sudan grass seeds were germinated on cheesecloth and transferred when large enough to facilitate handling without injury. The bean seeds were germinated in black sand and transplanted as soon as was practicable.

All the plants were given complete nutrients for 2 weeks. The following solutions were used:

	TOMATO	SUDAN GRASS	BEAN
$Ca(NO_3)_2$	.005M	.005M	.005M
KNO_3	.005M	.005M	.005M
$MgSO_4$	.002M	.002M	.002M
$CaCl_2$	.003M	.003M	——
KH_2PO_4	.001M	.001M	.002M

Iron (as $FeSO_4$) and standard amounts of copper, manganese, zinc, and boron were added.

After 2 weeks passed the solutions were changed, but the nutrients as listed above were maintained with the exception of the phosphate, which was added in the amount required in the experiment. The arsenic increments were added as planned, and the plants were selected for uniformity and thinned to three plants per crock for the bean and Sudan grass and two plants for the tomato. All solutions were changed weekly, and the levels of all salts were maintained as required in the experiment.

Plants which did not live until the end of the experiment were removed when they died. All others were allowed to grow for 3 to 4 weeks after the original treatment; then they were harvested. Green weights of the plant tops were taken, after which the plants were dried and dry weights taken. The material was ground in a Wiley mill and stored for subsequent arsenic and phosphate analyses.

Methods of analysis.—The method of Cassil and Wichmann (1939) was used in making the arsenic determinations reported in this paper. For the phosphate determinations, the Truog and Meyer (1929) modification of the Deniges method was used.

The dry plant material was digested as follows: Two grams or less of the sample were added to 125 cc. Erlenmeyer flasks, followed by 10 cc. of H_2SO_4 and 20 cc. of HNO_3. The flasks were allowed to stand for several hours, then heated slowly. Five-cc. increments of HNO_3 were added, and the digestion continued until the solution was clear and yellow. A final 5 cc. of HNO_3 was added with 5 drops of perchloric acid and heat was applied until dense white SO_3 fumes were evolved. The flask was removed and cooled, and the solution made up to 125 cc. From this, suitable aliquots were taken for the arsenic and phosphate determinations.

DATA AND DISCUSSION

Part I. Comparative Toxicity of Trivalent and Pentavalent Arsenic

In Tables 1, 2, and 3 are presented data for experiments using the three species treated with sodium arsenate (Na_2HAsO_4.

TABLE 1. TOMATO

DATA FOR THE ACCUMULATION OF ARSENIC (AS PPM As_2O_3) AND PHOSPHORUS (AS PER CENT OF DRY WEIGHT), AS WELL AS DRY WEIGHTS OF PLANTS GROWN IN SOLUTIONS CONTAINING VARIOUS INCREMENTS OF PENTAVALENT ARSENIC (AS SODIUM ARSENATE) AT DIFFERENT PHOSPHATE LEVELS.

ARSENIC IN SOLUTION	DRY WEIGHT	ARSENIC IN PLANT	PHOSPHORUS IN PLANT
ppm As_2O_3	gm.	ppm As_2O_3	% dry wt.
Low phosphorus level (P = 10 ppm)			
0.0	27	trace	0.72
1	30	5.0	.67
2.5	34	10.6	.61
5	21	22.5	.75
10	18	42.2	.75
15	10	76.5	.72
20	10	81.3	.67
25	6	93.0	.50
30	3	106.3	.72
40	2	162.5	.60
Medium phosphorus level (P = 60 ppm)			
0.0	28	0	.75
6	29	6.7	.72
15	19	17.2	.84
30	18	49.7	.84
60	9	74.1	.69
90	4	120.1	.63
120	2	193.7	.60
High phosphorus level (P = 120 ppm)			
0.0	28	trace	.72
12	23	12.2	.78
30	19	26.6	.69
60	11	61.3	.64
120	6	103.9	.60

7 H_2O), and in Tables 4, 5, and 6 the data for the same species treated with sodium arsenite ($NaAsO_2$).

Since it will be shown later that the phosphorus level has an important influence on arsenic toxicity, comparisons between arsenate and arsenite must be made within series of similar phosphorus concentration. Comparisons of the arsenate and arsenite experiments at the medium phosphorus level (P = 60 ppm) indicate marked differences between the action of pentavalent and of trivalent forms.

The tomato plants growing in 60 ppm of pentavalent arsenic accumulated 74.1 ppm of arsenic in their tops, yet were normal except in size. Tomato plants grown in solutions containing 90 ppm and 120 ppm of pentavalent arsenic lived to the end of the experiment despite accumulations of 120 ppm and 194 ppm of arsenic in their tops. The lethal concentration was between 120 ppm and 150 ppm in the culture solution. In the arsenite series, on the other hand, concentrations of 7 ppm and 11 ppm in the solution very nearly stopped growth, although the plants on analysis showed only 12.5 ppm and 24.1 ppm of arsenic respectively in their tops. Even the low level of 3¼ ppm in the culture caused marked stunting; the lethal concentration was 11 to 15 ppm. Approximately 10 times as much pentavalent arsenic is required in the culture solution and in the plant tissue as trivalent arsenic to produce equivalent injuries to tomato plants.

TABLE 2. SUDAN GRASS

DATA FOR THE ACCUMULATION OF ARSENIC (AS PPM As_2O_3) AND PHOSPHORUS (AS PER CENT OF DRY WEIGHT), AS WELL AS DRY WEIGHTS OF PLANTS GROWN IN SOLUTIONS CONTAINING VARIOUS INCREMENTS OF PENTAVALENT ARSENIC (AS SODIUM ARSENATE) AT DIFFERENT PHOSPHATE LEVELS.

ARSENIC IN SOLUTION	DRY WEIGHT	ARSENIC IN PLANT	PHOSPHORUS IN PLANT
ppm As_2O_3	gm.	ppm As_2O_3	% dry wt.
Low phosphorus level (P = 10 ppm)			
0.0	40	trace	0.61
1	23	13.5	.53
2.5	21	19.1	.56
5	11	47.4	.42
10	5	67.2	.44
15	2	88.8	.42
20	2	103.1	.53
25	2	139.1	.54
Medium phosphorus level (P = 60 ppm)			
0.0	37	trace	.72
6	29	29.4	.75
15	18	41.0	.75
30	8	74.1	.59
60	4	98.4	.56
90	2	513.1	.66
High phosphorus level (P = 120 ppm)			
0.0	36	trace	.84
12	28	12.8	.91
30	20	49.7	.78
60	14	84.4	.59
120	6	142.3	.52

TABLE 3. BEAN

DATA FOR THE ACCUMULATION OF ARSENIC (AS PPM As_2O_3) AND PHOSPHORUS (AS PER CENT OF DRY WEIGHT), AS WELL AS DRY WEIGHTS OF PLANTS GROWN IN SOLUTIONS CONTAINING VARIOUS INCREMENTS OF PENTAVALENT ARSENIC (AS SODIUM ARSENATE) AT DIFFERENT PHOSPHATE LEVELS.

ARSENIC IN SOLUTION	DRY WEIGHT	ARSENIC IN PLANT	PHOSPHORUS IN PLANT
ppm As_2O_3	gm.	ppm As_2O_3	% dry wt.
Low phosphorus level (P = 10 ppm)			
0.00	50	trace	0.64
.1	47	2.5	.55
.25	38	2.8	.51
.5	38	2.5	.50
1.5	28	10.3	.66
2.0	15	13.7	.58
2.5	11	20.0	.53
Medium phosphorus level (P = 60 ppm)			
0.0	44	trace	.59
.6	48	1.6	.59
1.5	43	2.7	.60
3	35	4.1	.63
6	38	5.1	.66
9	26	7.2	.61
High phosphorus level (P = 120 ppm)			
0.0	57	trace	.63
1.2	54	1.9	.59
3	38	2.7	.66
6	37	5.0	.63
12	16	38.0	.72

The Sudan grass plants growing in solutions containing 30 ppm and 60 ppm of pentavalent arsenic were apparently normal except for size, although they accumulated 74.1 and 98.4 ppm of arsenic in their tops. Marked injury was noted at 90 ppm; the lethal concentration was between 90 ppm and 120 ppm. With trivalent arsenic, however, a concentration as low as 3¼ ppm of arsenic in the culture solution resulted in cessation of growth, although the plant tops showed only 14.9 ppm of arsenic. The lethal concentration in the culture solution of the trivalent arsenic was between 11 ppm and 15 ppm. Sudan grass can tolerate approximately 10 times as much pentavalent arsenic in the culture solution and in their tissues as trivalent arsenic.

The bean plants were very intolerant of arsenic in any form. They grew quite normally, however, in solutions containing 9 ppm of pentavalent arsenic, from which they accumulated 7.2 ppm of arsenic in their tops. The lethal concentration was between 12 ppm and 15 ppm of pentavalent arsenic. On the other hand, growth was prevented by a concentration of 2.25 ppm to 2.85 ppm of trivalent arsenic, despite an accumulation of only 4.9 ppm of arsenic in their tops. The lethal concentration of trivalent arsenic in the culture solution was between 2.85 ppm and 3.6 ppm. Trivalent arsenic is roughly four times as toxic to bean plants as is the pentavalent form.

Comparisons made between the arsenate and arsenite series at the high and low phosphorus levels show results similar to those discussed above for the intermediate phosphorus level.

The two forms of arsenic differ not only in lethal concentrations, but also in their immediate action on plant tissues. Trivalent arsenic has a violent action, causing complete disintegration of the roots and burning of the tops in 1 or 2 days in lethal concentrations. Pentavalent arsenic, on the other hand, often takes several days to produce any response other than wilting, even in concentrations that eventually prove lethal.

Part II. The Effect of Different Phosphorus Levels on the Toxicity of Trivalent and Pentavalent Arsenic

It was suggested by Hurd-Karrer (1939) that a relationship exists between arsenic toxicity and phosphorus availability. She used sodium arsenate in culture solutions at different phosphorus levels on studies with the oat plant and came to the conclusion that "in general, the arsenic was definitely toxic in the presence of less than four times as much phosphorus but non-toxic when there was more than four times as much."

Based on that observation, investigations were undertaken to compare the effect of

phosphorus level on trivalent and pentavalent arsenic to determine whether the decrease in toxicity was due to decreased absorption of the toxic element in the presence of large amounts of phosphorus or whether it was due to some inhibitory effect which phosphorus might have on arsenic toxicity after absorption by the plant tissues.

Bean, Sudan grass, and tomato plants were grown in culture solutions at three phosphorus levels—10 ppm, 60 ppm, and 120 ppm—and subjected to treatment with sodium arsenate and sodium arsenite.

In Tables 1, 2, and 3 are recorded the data for the tests with *pentavalent* arsenic. It can be seen that an increase in the phosphorus level markedly reduced the amount of pentavalent arsenic absorbed, and resulted in better growth. For example, the tomato plants grown in low-phosphorus solutions containing 30 ppm of arsenic contained 106.3 ppm of arsenic in their tops, as compared to 49.7 ppm and 26.6 ppm in plants grown in medium- and high-phosphorus solutions, respectively, containing similar amounts of arsenic.

Similarly, increases in the phosphorus level reduced the absorption of arsenic by Sudan grass. The analyses of plant tops showed 88.8 ppm, 41.0 ppm, and 20.0 ppm of arsenic from the low-, medium-, and high-phosphorus solutions containing 15 ppm of arsenic.

The relationship of the phosphorus level to arsenic absorption by the bean is not so decisive. The bean has a very small range of tolerance to arsenic and, as a result, the magnitude of the differences between the various cultures is correspondingly small. The beans showed, for example, 10.3 ppm, 2.7 ppm, and 2.0 ppm of arsenic in their tops when grown in low-, medium-, and high-phosphorus solutions, respectively, containing 1.5 ppm of arsenic.

As might be expected, a reduction in the absorption of the toxic element by the plant resulted in better plant growth. The controls showed no significant differences in the dry weights at the three phosphorus levels, indicating that 10 ppm of phosphorus were adequate for the three plants studied. Analysis of the plant tops showed no significant differences among plants grown in low-, medium-, and high-phosphorus levels. Furthermore, the dry weights seemed to correlate with the arsenic concentration in the plant, irrespective of the phosphorus level of the culture solution. These considerations would seem to indicate that the phosphorus in the culture solution is effective in inhibiting the absorption of pentavalent arsenic by the plant but not in reducing the toxicity of the element within the plant.

Hurd-Karrer (1939) suggested that arsenates would be non-toxic if the P : As ratio were more than 4 : 1. Although a high phosphorus level greatly reduced the toxic effects of a given concentration of arsenic in the culture solution by reducing its absorption by the three plants studied here, it did not prevent injury. For example, tomatoes growing in solutions in which the P : As ratio was 10 : 1 (120 ppm : 12 ppm) had a dry weight of 23 grams as compared to 28 grams in the control—a reduction of 18 per cent. Sudan grass in solutions containing 120 ppm of phosphorus and 12 ppm of arsenic (P : As = 10 : 1) weighed 28.5 grams as compared to 36 grams in the control—a reduction of 21 per cent. Bean plants growing in solutions containing 6 ppm of arsenic and 120 ppm of phosphorus (P : As = 20 : 1) weighed 37 grams as compared to 57 grams in the control—a reduction of 35 per cent. A high phosphorus level reduces but does not prevent the absorption of pentavalent arsenic. The degree of injury depends on the amount of the toxic element absorbed.

The data for the studies made with *trivalent* arsenic are recorded in Tables 4, 5, and 6. The results indicate that the action

TABLE 4. TOMATO

DATA FOR THE ACCUMULATION OF ARSENIC (AS PPM As_2O_3) AND PHOSPHORUS (AS PER CENT OF DRY WEIGHT), OF PLANTS GROWN IN SOLUTIONS CONTAINING VARIOUS INCREMENTS OF TRIVALENT ARSENIC (AS SODIUM ARSENITE) AT DIFFERENT PHOSPHORUS LEVELS.

ARSENIC IN SOLUTION	DRY WEIGHT	ARSENIC IN PLANT	PHOSPHORUS IN PLANT
ppm As_2O_3	gm.	ppm As_2O_3	% dry wt.
Low phosphorus level (P = 10 ppm)			
0.00	29	trace	0.66
.25	30	trace	.67
.50	31	trace	.69
.75	30	trace	.66
1.00	28	1.6	.77
1.75	26	1.3	.76
2.50	20	3.9	.78
3.25	10	4.7	.70
4.00	9	10.9	.81
5.00	4	12.0	.81
Medium phosphorus level (P = 60 ppm)			
0.00	32	trace	.75
1.00	29	trace	.77
2.00	24	3.3	.75
3.25	9	6.7	.84
7.00	1	12.5	.69
11.00	1	24.1	.50
High phosphorus level (P = 120 ppm)			
0.00	33	trace	.85
1.00	28	trace	.88
3.25	7	7.8	.88
7.25	3	14.7	.84

of phosphorus on the absorption of trivalent arsenic is quite different from its action on pentavalent arsenic. From a given concentration of trivalent arsenic, the tomato plants absorbed approximately the same amount of the toxic element, irrespective of the phosphorus level, and showed equal degrees of injury. In the studies with Sudan grass, the medium- and the high-phosphorus levels reduced the absorption of arsenic over that absorbed from the low level of phosphorus, with a corresponding reduction in injury. In the studies with the bean plants, the phosphorus level had some effect on the absorption of arsenic as shown in the analysis of the plant material, although it should be noted that the differences are so small as to be insignificant.

These studies reveal, therefore, that the form in which the arsenic occurs is an important factor in determining the effect of phosphorus. Hurd-Karrer (1937) in her studies on the antagonism of related ions found that sulfates more effectively reduced the absorption of selenium from selenates than from selenites. From these results she suggested that "by analogy, phosphates would be expected to have less effect on the toxicity of arsenite than on that of arsenate" (1939). The studies reported in this paper confirm that supposition.

Part III. Toxic Levels of Arsenic in Certain Hawaiian Soils

It is well known that arsenicals, when applied to soil, are far less available to plants

TABLE 5. SUDAN GRASS

DATA FOR THE ACCUMULATION OF ARSENIC (AS PPM As_2O_3) AND PHOSPHORUS (AS PER CENT OF DRY WEIGHT), OF PLANTS GROWN IN SOLUTIONS CONTAINING VARIOUS INCREMENTS OF TRIVALENT ARSENIC (AS SODIUM ARSENITE) AT DIFFERENT PHOSPHORUS LEVELS.

ARSENIC IN SOLUTION	DRY WEIGHT	ARSENIC IN PLANT	PHOSPHORUS IN PLANT
ppm As_2O_3	gm.	ppm As_2O_3	% dry wt.
Low phosphorus level (P = 10 ppm)			
0.00	63	trace	0.44
.25	63	5.2	.36
.50	48	7.8	.59
.75	48	11.9	.45
1.00	32	18.6	.56
1.75	17	20.7	.56
2.50	5	23.1	.73
3.25	4	22.7	.48
4.00	2	42.5	.55
5.00	3	46.9	.88
Medium phosphorus level (P = 60 ppm)			
0.00	63	trace	.94
1.00	39	8.6	.58
2.00	24	10.9	.53
3.25	4	14.9	.56
7.00	3	27.5	.67
11.00	2	91.2	.81
High phosphorus level (P = 120 ppm)			
0.00	68	trace	.98
1.00	45	4.1	.88
3.25	18	12.8	.99
7.50	8	32.5	.77
15.00	2	87.5	.81

TABLE 6. BEAN

DATA FOR THE ACCUMULATION OF ARSENIC (AS PPM As_2O_3) AND PHOSPHORUS (AS PER CENT OF DRY WEIGHT), AS WELL AS DRY WEIGHTS, OF PLANTS GROWN IN SOLUTIONS CONTAINING VARIOUS INCREMENTS OF TRIVALENT ARSENIC (AS SODIUM ARSENITE) AT DIFFERENT PHOSPHORUS LEVELS.

ARSENIC IN SOLUTION	DRY WEIGHT	ARSENIC IN PLANT	PHOSPHORUS IN PLANT
ppm As_2O_3	gm.	ppm As_2O_3	% dry wt.
Low phosphorus level (P = 10 ppm)			
0.000	42	trace	0.53
.038	49	trace	.47
.075	58	trace	.44
.113	49	0.9	.44
.150	41	1.2	.50
.263	27	0.9	.69
.375	25	2.1	.63
.488	26	2.1	.56
.600	23	3.9	.63
.750	30	3.7	.50
Medium phosphorus level (P = 60 ppm)			
0.00	36	trace	.70
.3	34	trace	.70
.49	27	trace	.63
1.05	27	1.3	.63
1.65	15	4.8	.69
2.25	6	4.9	.69
2.85	5	7.0	.66
High phosphorus level (P = 120 ppm)			
0.00	31	trace	.63
.15	31	trace	.72
.49	30	trace	.59
1.13	15	trace	.66
2.25	5	3.3	.75

than they are when applied to culture solution. The degree to which arsenicals are fixed by the soil is a characteristic of the soil (Crafts and Rosenfels: 1939). The objectives of this part of the work are: first, to determine the growth reaction of certain crop plants to arsenic levels in two Hawaiian soils; second, to determine the amount of arsenic which these plants withdraw from the soil; and third, to determine whether or not it is practicable to use certain crop plants to lower the arsenic levels of those soils which have been rendered sterile to other crop plants.

Methods.—Two soils were used—one a red residual clay and the other a black alluvial soil. The red is a residual soil taken from the mountain slopes above Kailua, Oahu. It is an infertile soil which requires heavy fertilization for crop production. The black alluvial soil, taken from a papaya orchard near Kailua, is, on the other hand, extremely fertile. In fact, it was recommended to us by Dr. L. A. Dean, Soils Chemist, as being a soil whose available phosphorus level was so high that no more phosphorus could be fixed by it.[3] The growth of plants in the two soils reflected not only the difference in chemical composition, but also the difference in physical qualities, the black soil being very well adapted to pot work. These soils contained 14.7 ppm of native arsenic. This amount is added to the increments of soil arsenic shown in the accompanying tables.

The soil was dried thoroughly, screened, and ground in a plate mill. Samples of 500 grams each were weighed into No. 2 cans, after which arsenic as sodium arsenite was added in concentrations varying from 10 ppm to 3,000 ppm following the methods described by Crafts and Rosenfels (1939). The soil was allowed to dry thoroughly, after which it was removed, pulverized again, mixed, and returned to the can.

With the red soil, triplicate cans were used for each arsenic concentration for each of the three species, making a total of 225 cans. With the black soil, only one container was used for each of the two species used for each concentration of arsenic.

Tomato and Sudan grass seedlings were started on cheesecloth and transplanted to the cans when a few days old. Bean seeds were germinated in black sand and transplanted to the cans as soon as possible. With tomato and bean, two plants per can were used, and with Sudan grass five plants.

Drainage was provided by punching holes in the cans. A complete nutrient solution

[3] The phosphorus content of the two soils as extracted with 0.002N H_2SO_4 was 24 ppm for the red soil and 250 ppm for the black soil.

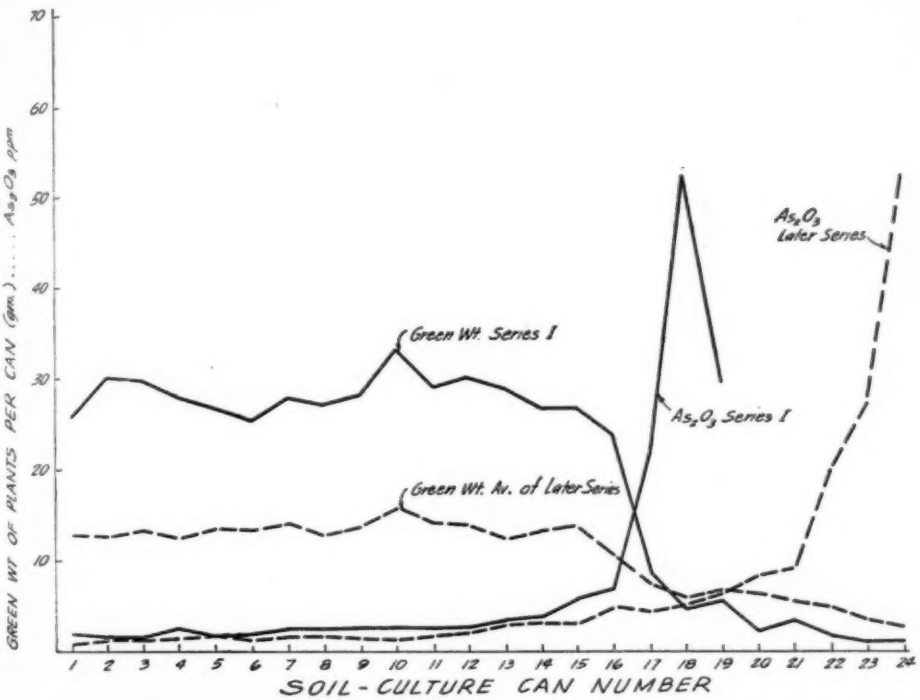

GREEN WT OF PLANTS PER CAN (gm.) ..... As_2O_3 ppm
70
60
50
40
30
20
10
As_2O_3 Later Series
Green Wt. Series I
As_2O_3 Series I
Green Wt. Av. of Later Series
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SOIL-CULTURE CAN NUMBER

FIG. 1. Green weights and arsenic content of tomato plants grown in red soil with arsenic content ranging from 15 ppm (Can 1) to 3,014 ppm (Can 24) of As_2O_3. The difference in levels of the two green-weight curves is due to the season in which the plants were grown and is not related to treatment. (For As_2O_3 increments, see Table 7.)

was added weekly to the soil. Each crop was allowed to grow 31 days from the time of transplanting, after which the plant tops were collected and green weights obtained. The material was dried, ground in a Wiley mill, and stored for future analysis.[4]

After the removal of one crop, the soil was allowed to dry thoroughly, after which each can was emptied and the soil pulverized, mixed, and returned. Roots were in each case returned to the bottom of the can.

Results and discussion: Tomato.—The data presented in Table 7 and shown in Figure 1 for tomato plants in red soil reveal the relative tolerance of young plants to soil arsenic up to approximately 514 ppm. At higher levels the ability of the plant to grow is drastically reduced to what would be growth failure in a commercial field.

At levels below 514 ppm, growth of the tomato is approximately at uniform levels, no matter what the level of arsenic in the soil. While there may be some slight evidence of stimulation, it is very inconclusive. The arsenic content of the plant tissues varies between 2 and 3 ppm for soil levels of arsenic between 15 and 314 ppm. Between this point and approximately 414 ppm of soil arsenic, the arsenic level rises gradually

[4] All the arsenic analyses made in connection with these soil studies were made by the Chemistry Department of the Experiment Station, Hawaiian Sugar Planters' Association. The department is directed by Dr. F. E. Hance, to whom sincere thanks are due.

TABLE 7. TOMATO–RED SOIL

YIELD DATA AND ARSENIC CONTENT OF TISSUES.

CAN NUMBER	As_2O_3 CONTENT OF SOIL	SERIES I		AVERAGE OF 4 LATER SERIES	
		Green weight of plants	As_2O_3 content of tissues	Green weight of plants	As_2O_3 content of tissues
	ppm	gm. per can	ppm	gm. per can	ppm
1	15	25.7	1.8	12.8	0.9
2	25	30.0	1.6	12.5	1.3
3	34	29.7	1.6	13.1	1.1
4	45	27.7	2.4	12.3	1.3
5	54	26.7	1.6	13.4	1.5
6	65	25.3	1.8	13.2	1.1
7	74	27.7	2.4	14.0	1.5
8	85	27.0	2.4	12.8	1.7
9	95	28.0	2.6	13.7	1.5
10	104	33.0	2.6	15.7	1.3
11	115	29.0	2.6	14.0	1.8
12	214	30.0	2.6	13.9	2.1
13	314	28.7	3.4	12.2	2.9
14	414	26.7	3.7	13.1	3.0
15	514	26.7	5.8	13.7	3.0
16	614	23.6	6.9	11.3	4.9
17	714	8.7	21.7	7.3	4.1
18	814	4.4	52.3	5.9	4.9
19	915	5.3	29.6	6.6	6.1
20	1014	2.0	.....	6.3	8.1
21	1514	3.1	.....	5.4	9.0
22	2014	1.6	.....	4.8	19.9
23	2515	0.9	.....	3.2	26.9
24	3014	0.8	.....	2.7	52.7

TABLE 8. TOMATO–BLACK SOIL

YIELD DATA AND ARSENIC CONTENT OF TISSUES.

CAN NUMBER	As_2O_3 CONTENT OF SOIL	SERIES I		AVERAGE OF 2 LATER SERIES	
		Green weight of plants	As_2O_3 content of tissues	Green weight of plants	As_2O_3 content of tissues
	ppm	gm. per can	ppm	gm. per can	ppm
1	15	29.0	.....	.....	.....
2	25	30.0	1.6	38.3	0.8
3	34	32.0	1.3	39.8	1.5
4	45	27.0	1.8	41.0	1.5
5	54	29.0	2.1	39.4	1.7
6	65	26.0	2.9	40.2	2.1
7	74	32.0	5.0	38.7	1.2
8	85	28.0	2.4	41.2	2.0
9	95	29.0	2.1	37.5	1.5
10	104	30.0	2.1	39.9	1.6
11	115	29.0	5.8	34.0	1.8
12	214	30.0	2.6	33.0	2.6
13	314	31.0	3.4	39.0	2.1
14	414	28.0	4.0	38.3	2.1
15	514	29.0	5.8	34.4	3.7
16	614	31.0	5.8	35.8	5.8
17	714	28.0	6.9	31.5	9.1
18	814	24.0	8.5	34.7	4.8
19	915	25.0	8.7	38.8	11.1
20	1014	30.0	9.2	31.5	15.8
21	1514	27.0	29.6	35.9	11.9
22	2014	25.0	64.2	29.5	30.5
23	2515	22.0	103.8	28.5	35.1
24	3014	20.0	76.1	32.3	50.0

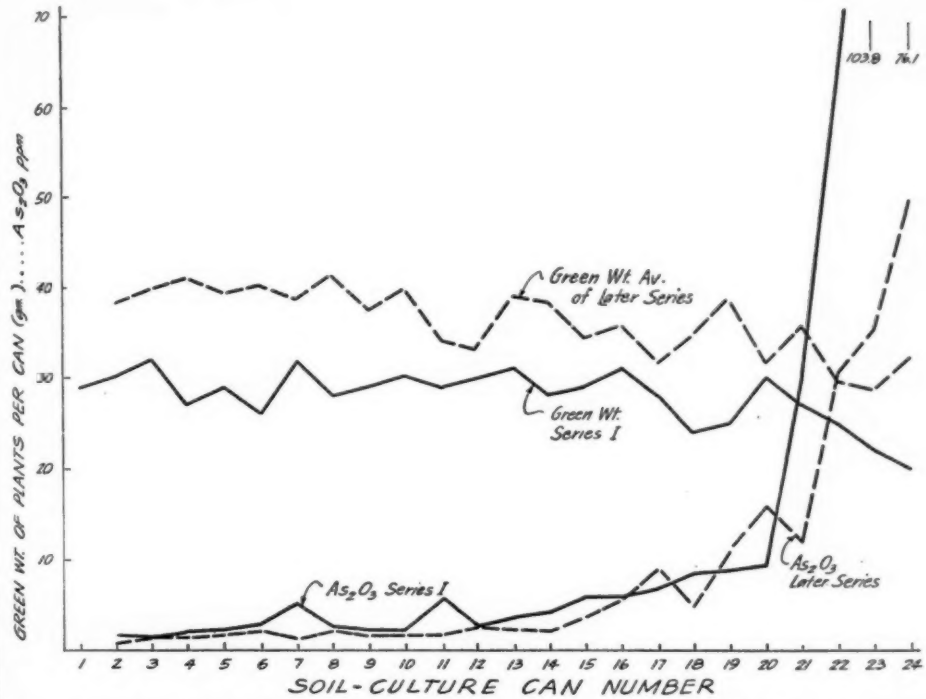


FIG. 2. Green weights and arsenic content of tomato plants grown in black soil with arsenic content ranging from 15 ppm (Can 1) to 3,014 ppm (Can 24) of As_2O_3. The difference in levels of the two green-weight curves is due to the season in which the plants were grown and is not related to treatment. (For As_2O_3 increments, see Table 8.)

from 3 ppm to 4 ppm. From higher levels of soil arsenic the plant absorbs increasing amounts of the poison, and this heavier absorption is reflected in greatly reduced growth.

Although the level of soil arsenic which might be described as critical for the tomato is the same for the later crops of plants as it is for the first crop, there is a striking difference in the amounts of arsenic absorbed by the later crops. Thus, the first crop in Can 18 contained about 52 ppm of arsenic, while the later crops in Can 18 absorbed about one tenth as much. A very much higher level of soil arsenic was necessary for the later crops to absorb 52 ppm. Two possible hypotheses suggest themselves. First, the fixation of arsenic by the soil may be a function not only of the nature of the soil but of time. Second, the soluble arsenic level of the soil may be reduced sufficiently by the first crop to reduce its absorption by later crops. However, the fact that growth in the first series as well as that in the later series is reduced in the same cultures does not lend support to the latter hypothesis.

Tomato: Black Soil.—The growth of young tomato plants in black soil, as shown in Table 8 and Figure 2, is very much better than it is in the red soil. The black soil is not only very fertile, but it possesses physical qualities which make it a better soil for pot work. The most striking contrast between the two soils is that in the black soil there

is no sharp curtailment of growth even in the cans having over 3,000 ppm of soil arsenic. Although the tomatoes growing in the cans at the upper concentration levels were slightly inferior in size to those in the lower levels, they were otherwise normal in every respect. They showed no premature drying or yellowing of leaves, their roots were as extensive as the others, and yet the arsenic levels in the plant tissues were very high. In Can 24, the first crop of plants appeared perfectly normal with good color, despite the fact that the crop contained 76.1 ppm of arsenic. Like those in the red soil, though to a lesser degree, later crops of tomatoes in black soil failed to extract as much arsenic from the high arsenic soil as did the first crop.

Sudan Grass: Red Soil.—Sudan grass plants, as shown in Table 9 and Figure 3, grew uniformly well in all cans up to Can 10, in which the arsenic content of the soil was 104 ppm. There is no suggestion of stimulation in the cultures having lower concentrations of arsenic. At the higher levels of soil arsenic, Sudan grass extracted substantially higher amounts of the poison than did the tomato. The first crop of grass absorbed larger quantities of arsenic at the higher levels than did later crops. In fact, each succeeding crop of Sudan absorbed less and less arsenic from the soil, but in each crop the depression of growth occurred at the same level of soil arsenic, a fact again pointing to the idea that the actual arsenic level in the plant is not causal, though it is

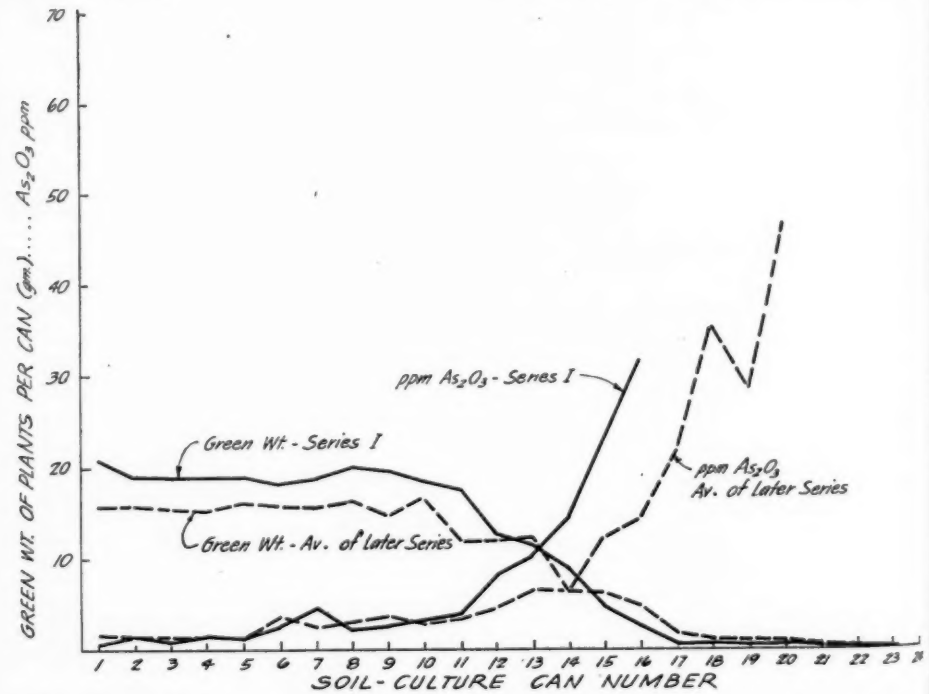

GREEN WT. OF PLANTS PER CAN (gm.)..... As_2O_3 ppm
70
60
50
40
30
20
10
ppm As_2O_3 - Series I
Green Wt. - Series I
ppm As_2O_3 Av. of later Series
Green Wt. - Av. of later Series
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SOIL-CULTURE CAN NUMBER

FIG. 3. Green weights and arsenic content of Sudan grass grown in red soil with arsenic content ranging from 15 ppm (Can 1) to 3,014 ppm (Can 24) of As_2O_3. The difference in levels of the two green-weight curves is due to the season in which the plants were grown and is not related to treatment. (For As_2O_3 increments, see Table 9.)

TABLE 9. SUDAN GRASS–RED SOIL

YIELD DATA AND ARSENIC CONTENT OF TISSUES.

CAN NUMBER	As_2O_3 CONTENT OF SOIL	SERIES I		AVERAGE OF 2 LATER SERIES	
		Green weight of plants	As_2O_3 content of tissues	Green weight of plants	As_2O_3 content of tissues
	ppm	gm. per can	ppm	gm. per can	ppm
1	15	20.8	0.5	15.7	1.5
2	25	19.0	1.6	15.7	1.5
3	34	18.7	0.8	15.5	1.3
4	45	19.0	1.6	15.1	1.6
5	54	19.0	1.3	16.0	1.3
6	65	18.3	2.6	15.8	3.8
7	74	18.7	4.5	15.6	2.4
8	85	20.0	2.1	16.3	3.0
9	95	19.7	2.6	14.8	3.7
10	104	18.3	.....	16.6	2.9
11	115	17.3	4.0	11.9	3.6
12	214	12.7	8.2	11.9	4.6
13	314	11.3	10.3	12.2	6.5
14	414	8.7	14.5	6.1	6.3
15	514	4.7	23.2	6.3	12.3
16	614	2.2	31.4	4.9	14.1
17	714	0.3	.....	1.7	21.8
18	814	0.6	.....	1.0	35.5
19	915	0.2	.....	0.9	28.1
20	1014	0.2	.....	0.8	46.1
21	1514	0.1	.....	0.4	.....
22	2014	.....	.....	0.2	.....
23	2515	.....	.....	0.2	.....
24	3014	.....	.....	0.1	.....

TABLE 10. SUDAN GRASS–BLACK SOIL

YIELD DATA AND ARSENIC CONTENT OF TISSUES.

CAN NUMBER	As_2O_3 CONTENT OF SOIL	SERIES I		AVERAGE OF 5 LATER SERIES	
		Green weight of plants	As_2O_3 content of tissues	Green weight of plants	As_2O_3 content of tissues
	ppm	gm. per can	ppm	gm. per can	ppm
1	15	25.3	2.4	36.8	1.3
2	25	22.6	5.5	33.2	1.2
3	34	23.8	5.0	31.6	1.8
4	45	25.8	4.2	32.4	1.6
5	54	23.2	3.4	33.6	1.2
6	65	24.6	3.4	32.8	2.2
7	74	27.3	.....	34.5	1.3
8	85	25.8	3.7	31.1	1.6
9	95	25.2	1.3	34.1	2.1
10	104	24.6	3.4	34.9	2.1
11	115	22.7	5.8	36.3	2.4
12	214	26.4	2.1	34.3	5.4
13	314	25.6	0.4	29.6	7.7
14	414	20.5	9.2	30.0	10.7
15	514	17.7	16.1	27.4	13.5
16	614	23.7	14.0	29.0	12.9
17	714	13.5	18.5	27.1	17.6
18	814	10.5	17.4	24.6	17.4
19	915	6.8	16.1	24.4	24.6
20	1014	10.9	24.0	17.6	27.3
21	1514	4.8	28.5	10.4	29.4
22	2014	0.9	44.6	2.4	56.1
23	2515	0.1	.....	1.0	86.5
24	3014	0.2	.....	0.7	.....

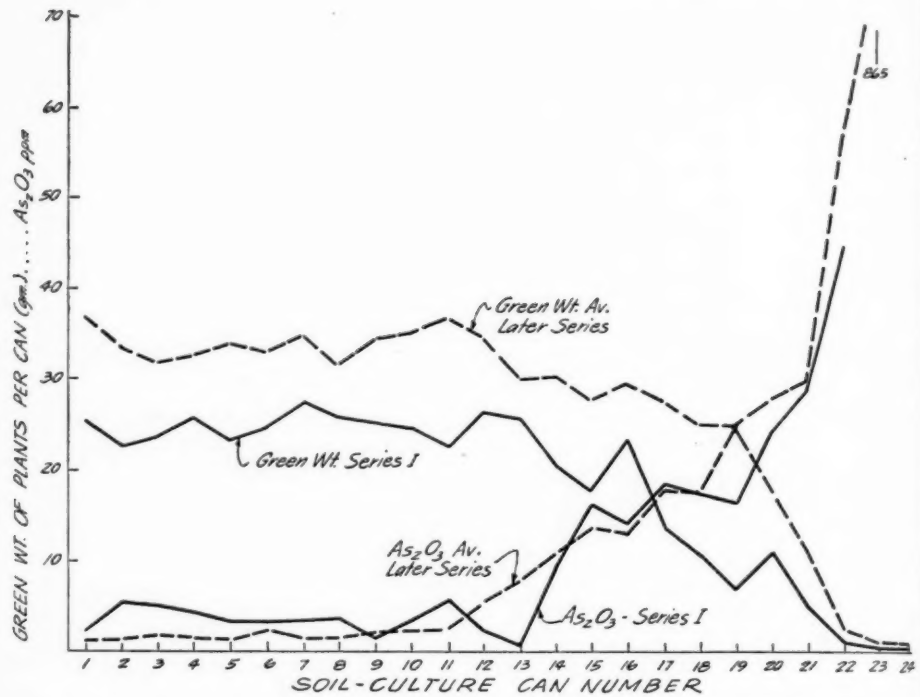

GREEN WT. OF PLANTS PER CAN (gm.)..... As_2O_3 ppm
70
60
50
40
30
20
10
Green Wt. Av. Later Series
Green Wt. Series I
As_2O_3 Av. Later Series
As_2O_3 - Series I
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SOIL-CULTURE CAN NUMBER

FIG. 4. Green weights and arsenic content of Sudan grass grown in black soil with arsenic content ranging from 15 ppm (Can 1) to 3,014 ppm (Can 24) of As_2O_3. The difference in levels of the two green-weight curves is due to the season in which the plants were grown and is not related to treatment. (For As_2O_3 increments, see Table 10.)

associated with the depression of growth.

Sudan Grass: Black Soil.—The growth of Sudan grass in black soil, as shown in Table 10 and Figure 4, was much more luxuriant than in the red soil. Furthermore, in the black soil normal growth occurred at much higher levels of soil arsenic, despite high tissue levels of arsenic. Unlike the curve for the tomato crops, there was a decided break in that of the Sudan grass series. Above Can 16 (614 ppm of soil arsenic) growth was progressively more difficult, and at the soil arsenic level of 2,014 ppm (Can 22) there was no growth.

Although Sudan grass in culture solution appeared as tolerant to arsenic as was the tomato, it is quite clear that in soils, Sudan grass is much less tolerant of arsenic than is the tomato. This difference in the soil seems only partly related to the ability of Sudan grass to extract higher levels of arsenic from a given soil. (Compare the arsenic levels in Figures 2 and 4 from Cans 13 to 20, in which growth of Sudan grass was still appreciable.) It is also partly related to a difference in the manner in which the plants hold the arsenic within their tissues. Thus, when the tomatoes growing in the black soil had over 20 ppm within their tissues, their growth was nearly normal. At the same tissue levels the growth of Sudan grass was nearly stopped. Thus, tolerance to soil arsenic involves root tolerance as well as tissue tolerance. Probably, root tolerance is

determined in part by the nature of the root structure and in part by the intimacy as well as nature of the contact between the root surface and the soil surface bearing the arsenic. Tissue tolerance, on the other hand, may be related in part to protoplasmic structure and in part to the form in which the arsenic is held within the protoplasm after it is absorbed.

Bean: Red Soil.—The bean plant (see Table 11 and Figure 5), which in culture solution was the most susceptible of the three plants to arsenic injury, showed a tolerance to soil arsenic only slightly below that of the tomato, but considerably above that of Sudan grass.

For the bean, as for the tomato and Sudan grass, although the level of soil arsenic at which growth was sharply curtailed was the same for the first crop as for later crops, the actual amount of arsenic absorbed was greater in the first crop than in later crops. Also, the differences in the amounts of arsenic absorbed by the various crops are not all related to the differences in growth made.

GENERAL DISCUSSION

It is apparent that production of crops in heavy Hawaiian soils which have been contaminated with the herbicide sodium arsenite will be affected variously depending on the particular crop. Furthermore, crops which may be looked upon as tolerant to arsenic when grown in culture solution may become relatively susceptible to fixed arsenic in the soil. In culture solutions, the bean plant was by far the most susceptible of the three plants used, whether the arsenic was trivalent or pentavalent. The tomato was the most resistant toward pentavalent arsenic, but was about equal to Sudan grass in resistance to trivalent arsenic. In soil cultures, however, Sudan grass was considerably less resistant to sodium arsenite than either of the other

TABLE 11. BEAN–RED SOIL

YIELD DATA AND ARSENIC CONTENT OF TISSUES.

CAN NUMBER	As_2O_3 CONTENT OF SOIL	SERIES I		AVERAGE OF 2 LATER SERIES	
		Green weight of plants	As_2O_3 content of tissues	Green weight of plants	As_2O_3 content of tissues
	ppm	gm. per can	ppm	gm. per can	ppm
1	15	18.7	0.5	24.3	1.5
2	25	18.0	1.1	23.7	1.5
3	34	19.0	1.8	25.9	1.8
4	45	17.3	2.4	22.8	2.2
5	54	20.7	2.9	23.5	5.0
6	65	24.0	7.9	27.5	1.8
7	74	24.7	9.0	28.0	2.0
8	85	26.7	6.9	25.2	3.2
9	95	22.7	4.8	25.9	2.1
10	104	22.3	3.4	23.0	1.7
11	115	22.3	3.7	22.8	2.1
12	214	22.0	5.5	26.7	2.5
13	314	14.0	6.3	22.7	3.7
14	414	18.0	10.3	21.2	6.9
15	514	11.0	14.0	14.2	6.6
16	614	7.7	26.4	9.5	6.9
17	714	6.3	.....	11.1	10.8
18	814	9.0	24.6	6.8	12.8
19	915	6.0	35.4	6.1	12.9
20	1014	2.5	.....	4.2	12.8
21	1514	2.3	.....	3.2	15.7
22	2014	1.1	.....	2.0	25.1
23	2515	0.7	.....	1.6	32.7
24	3014	0.2	.....	1.5	46.5

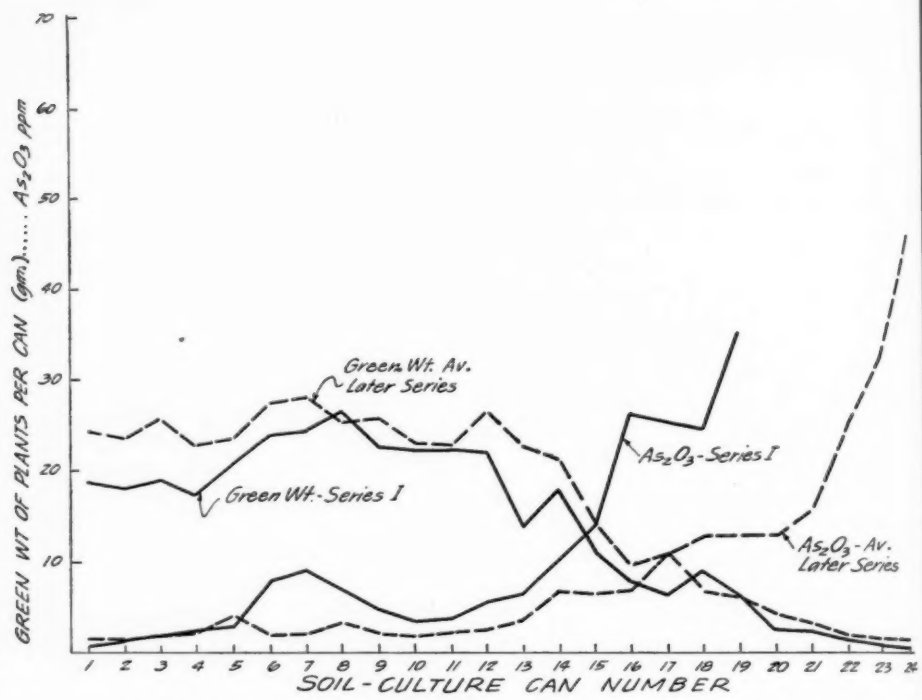

GREEN WT OF PLANTS PER CAN (gm)..... As_2O_3 ppm
70
60
50
40
30
20
10
Green Wt. Av. Later Series
Green Wt.-Series I
As_2O_3-Series I
As_2O_3-Av. Later Series
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SOIL-CULTURE CAN NUMBER

FIG. 5. Green weights and arsenic content of bean plants grown in red soil with arsenic content ranging from 15 ppm (Can 1) to 3,014 ppm (Can 24) of As_2O_3. The difference in levels of the two green-weight curves is due to the season in which the plants were grown and is not related to treatment. (For As_2O_3 increments, see Table 11.)

two. In the red soil, the arsenic concentrations which were toxic to Sudan grass, bean, and tomato were approximately 110, 250, and 550 ppm, respectively. In pounds per acre foot of dried soil, these figures become roughly 220, 500, and 1,100 pounds, respectively.

Perhaps the fact that Sudan grass is a vigorous feeder especially of fixed phosphorus in such soils is related to its greater sensitivity to soil arsenic, which probably is similarly fixed. Such an observation has support in the data presented for red soils, which demonstrate that Sudan grass extracted higher levels of arsenic from Cans 10 to 16 than did either of the other two plants. Both tomatoes and beans when grown on Hawaiian soils are fertilized heavily with phosphates in order to obtain good growth. The large grasses, however, seem to be able to take their phosphorus even though it is highly fixed.

It is doubtful whether arsenic which is applied to soils as trivalent arsenic remains trivalent after it has been in the soil for some time. Although no direct pertinent data are available from this study, indirect data may be obtained from the arsenic levels attained by the Sudan grass and tomato plants growing on the black soil. Tomato plants in black soil (Can 22) which were apparently normal contained up to 104 ppm of arsenic. Sudan grass plants in black soil in Cans 21 and 22 contained between 30

and 86 ppm of arsenic. Yet when these were grown in culture solution, only very much lower levels of trivalent arsenic were tolerated. The amounts of arsenic absorbed from the soil were more in line with the amounts of pentavalent arsenic absorbed from culture solution. It cannot be presumed, however, that after arsenic is absorbed in the pentavalent form, it remains as an inorganic compound after it becomes a part of the plant's metabolism.

The claim which has been made by many that arsenic at proper levels is stimulating to plant growth is not substantiated by the data presented here. Neither in water culture nor in soil culture is there any certain evidence of such stimulation. What slight gains from arsenic there may be are infinitesimal compared with the losses which are certain to come after the arsenic content passes critical levels.

The arsenic which was added to the soil cans was not greatly reduced in amount either by the growth of the plants or by drainage which was provided. Even the large amounts of arsenic contained in the tomato plants grown in the high arsenic cans represent very small proportions of the total amount of arsenic in the soil. To calculate the time needed to extract the arsenic from the soil through continued use of tomato plants, assuming the highest extraction observed in these tests, would require something over 100 crops. It is far better to stop the use of arsenic before critical levels are reached. It is apparent from this work, as well as from that of others, that no matter how large or how small the annual increments to the soil may be, substantially all of the arsenic remains in the tilled layer. Reducing the increment of arsenic applied merely prolongs the time of grace.

One observation needing to be brought into sharp focus is that, as shown in all figures in the text, the point of sterilization for a given crop is very much higher than the point at which crop production begins to suffer curtailment because of accumulated arsenic.

In red soil, Sudan grass began to suffer growth curtailment at about 115 ppm As_2O_3, the tomato at about 614 ppm, and the bean at about 314 ppm. From these respective points on, the increasing curtailment varies for each crop. For the tomato the further drop is precipitous, less so for the bean, and still less so for Sudan grass.

Sobering is the report from Queensland by Kerr (1939) that soil arsenic at the level of 600 ppm resulted in complete growth failure of sugar cane. In times of low prices for agricultural produce, even a 5 per cent curtailment of production due to soil arsenic may well mean the difference between profitable and unprofitable operation.

Studies carried on elsewhere have yielded some treatments which may be useful in correcting arsenic toxicity. The use of heavy phosphate applications, lime, iron oxide, and organic matter (perhaps filter cake) have shown promise of reducing the toxicity of arsenic excesses. None of these treatments reduces the arsenic content of the soil. Furthermore, most of these treatments are costly. Whether a single treatment is effective for any length of time remains to be determined.

There is only one permanent solution to the problem of arsenic accumulation so far as present-day information is concerned, and that is the cessation of arsenic applications. Substitution of other herbicides or other weed-control practices which at the moment may seem somewhat more costly may be the cheapest in the long run. Certainly there can be no reconciliation of a program of arsenic applications to the soil with any long-range view of agriculture.

SUMMARY

1. Studies made with plants treated with sodium arsenate and sodium arsenite in cul-

ture solutions show trivalent arsenic to be approximately 10 times as toxic to Sudan grass and tomato plants as the pentavalent form and approximately four times as toxic to bean plants as the pentavalent form. The trivalent form acts more quickly and violently on plant tissues.

2. Studies on the relationship of the phosphorus level to the toxicity of *pentavalent* arsenic show that an increase in the phosphorus level materially reduces the absorption of arsenic by bean, Sudan grass, and tomato plants. The phosphorus was found to have little or no effect on the toxicity of the element after it has been taken into the plant.

The phosphorus had little, if any, effect on the absorption of *trivalent* arsenic from culture solution by bean, Sudan grass, and tomato plants.

3. Results are presented for several crops of Sudan grass, tomato, and bean plants in a re-cropping experiment with red and black soils treated with increments of sodium arsenite. It was found that as time elapsed, more and more of the arsenic was fixed by the soil, a fact indicated by a reduction in the amount of arsenic found in the plant tops. Growth curtailment, however, was observed to take place each time at the same levels of soil arsenic, irrespective of the levels of arsenic absorbed.

It was found that the plant species varied in the ability to withdraw arsenic from the soil medium, tomato and bean being low and Sudan grass high in ability to withdraw the element.

4. Sudan grass and tomato plants were grown in a black alluvial soil treated with sodium arsenite, and the results were compared to those in the red soil experiment. Marked differences were found in the response of the plants to a certain concentration of arsenic in the two soils.

5. Whereas in culture solution Sudan grass was as tolerant to arsenic as the tomato and much more so than the bean, in soil, Sudan grass was less tolerant to arsenic than either.

6. The removal of soil arsenic by crops which are tolerant to arsenic will at best be a very slow process.

REFERENCES

ALBERT, W. B., and C. H. ARNDT. Report. *So. Carolina Agr. Expt. Sta. Ann. Rpt.* 44: 47–50, 1931.

———, and W. R. PADEN. Calcium arsenate and unproductiveness in certain soils. *Science* 73: 662, 1931.

BERTINSANS, H., and V. ROS. The use of arsenical compounds in the treatment of vineyards. *Rev. d'Hyg. et Police Sanit.* 30: 281–286, 1908. (Abstract in *Expt. Sta. Rec.* 20: 459, 1909.)

BOUILHAC, R. Effect of arsenic on plants. *Soc. Bot. de France Bul.* 46: 64, 1899. (Abstract in *Expt. Sta. Rec.* 11: 1016, 1900.)

BRENCHLEY, W. E. The action of certain compounds of zinc, arsenic, and boron on the growth of plants. *Ann. Bot.* 28: 283–301, 1914 (*a*).

——— *Inorganic plant poisons and stimulants.* x + 110 p. Cambridge Univ. Press, 1914 (*b*).

CASSIL, C. C., and H. J. WICHMANN. A rapid volumetric micromethod for determining arsenic. *Assoc. Off. Agr. Chem. Jour.* 22: 436–445, 1939.

CHORLEY, J. K., and R. MCCHLERY. Experiments on the toxicity to fowls of arsenate of soda and poisoned locusts. *Rhodesia Agr. Jour.* 32: 322–326, 1935.

COOPER, H. P., W. R. PADEN, E. E. HALL, W. B. ALBERT, W. B. ROGERS, and J. A. RILEY. Effects of calcium arsenate on the productivity of certain soil types. *So. Carolina Agr. Expt. Sta. Ann. Rpt.* 44: 28–36, 1931.

COULSON, E. J., R. E. REMINGTON, and K. M. LYNCH. Toxicity of naturally occurring arsenic in foods. *Science* 20: 230–231, 1934.

——— Metabolism in the rat of the naturally occurring arsenic of shrimp as compared with arsenic trioxide. *Jour. Nutr.* 10: 225–270, 1935.

CRAFTS, A. S., and R. S. ROSENFELS. Toxicity studies with arsenic in eighty California soils. *Hilgardia* 12: 177–200, 1939.

FRANKE, K. W., and A. L. MOXON. A comparison of the minimum fatal doses of selenium, tellurium, arsenic, and vanadium. *Jour. Pharmacol. and Expt. Ther.* 58: 454–459, 1936.

GREAVES, J. E. The occurrence of arsenic in soils. *Biochem. Bul.* 2: 519–523, 1913 (*a*).

—— The influence of arsenic upon the biological transformation of nitrogen in soils. *Biochem. Bul.* 3: 2–16, 1913 (*b*).

—— Stimulating influence of arsenic upon the nitrogen-fixing organisms of the soil. *Jour. Agr. Res.* 6: 389–416, 1916.

—— The influence of arsenic on the bacterial activities of a soil. *Sci. Monthly* 5: 204–209, 1917.

—— The arsenic content of soils. *Soil Sci.* 38: 355–362, 1934.

——, and H. P. ANDERSON. The influence of arsenic upon the nitrogen-fixing powers of the soil. (Abstract in *Expt. Sta. Rec.* 32: 720, 1915.)

GREEN, H. H., and N. H. KESTELL. Behavior of bacteria toward arsenic. *South African Jour. Sci.* 15: 369–374, 1919.

GROVES, KERMIT, E. C. MCCULLOCH, and J. L. ST. JOHN. Relative toxicity to swine of lead arsenate spray residue, lead arsenate, lead acetate, and arsenic trioxide. *Jour. Agr. Res.* 73: 159–166, 1946.

HEADDEN, W. P. Arsenical poisoning of fruit trees. *Colo. Expt. Sta. Bul.* 131: 3–27, 1908.

—— Arsenical poisoning of fruit trees. *Jour. Econ. Ent.* 2: 239–245, 1909.

—— Arsenical poisoning of fruit trees. *Colo. Expt. Sta. Bul.* 157: 3–56, 1910.

HEGGENESS, H. Arsenic toxicity to plants. *Hawaii Agr. Expt. Sta. Rpt. 1939:* 77, 1940.

HURD-KARRER, A. M. Inhibition of arsenic injury to plants by phosphorus. *Wash. Acad. Sci. Jour.* 26: 180–181, 1936.

—— Comparative toxicity of selenates and selenites to wheat. *Amer. Jour. Bot.* 24: 720–728, 1937.

—— Antagonism of certain elements essential to plants toward chemically related toxic elements. *Plant Physiol.* 14: 9–30, 1939.

KARDOS, L. T., S. C. VANDECAVEYE, and N. BENSON. Investigation of the causes and remedies of the unproductiveness of certain soils following the removal of mature trees. *Wash. Agr. Expt. Sta. Bul.* 394: 21–27, 1940.

KEATON, C. M. Oxidation-reduction potentials of arsenate–arsenite systems in sand and soil mediums. *Wash. State Col. Res. Studies* 6: 99–101, 1938.

——, and L. T. KARDOS. Oxidation–reduction potentials of arsenate–arsenite systems in sand and soil mediums. *Soil Sci.* 50: 189–207, 1940.

KERR, W. H. Damage to cane soils by arsenic. *Cane Growers' Quart. Bul.* 6: 189, 1939.

LYTTKENS, E. Influence of arsenic on plants. (Abstract in *Expt. Sta. Rec.* 5: 1011, 1895.)

MCGEORGE, W. T. *The effect of arsenite of soda on the soil.* Hawaii Agr. Expt. Sta., Press Bul. 50: 16 p., 1915 (*a*).

—— Fate and effect of arsenic applied as a spray for weeds. *Jour. Agr. Res.* 5: 459–463, 1915 (*b*).

MACHLIS, L. Accumulation of arsenic in the shoots of Sudan grass and bush bean. *Plant Physiol.* 16: 521–544, 1941.

MORRIS, H. E., and D. B. SWINGLE. Injury to growing crops caused by application of arsenical compounds to the soil. *Jour. Agr. Res.* 34: 59–78, 1927.

PADEN, W. R., and W. B. ALBERT. Effect of the addition of arsenical compounds to soils. *So. Carolina Agr. Expt. Sta. Ann. Rpt.* 43: 129, 1930.

REED, J. F., and M. B. STURGIS. Toxicity from arsenic compounds to rice on flooded soils. *Amer. Soc. Agron. Jour.* 28: 432–436, 1936.

REICHERT, F., and R. A. TRELLES. Presence of arsenic as a normal element in vegetable soils. (Abstract in *Expt. Sta. Rec.* 46: 814, 1922.)

STOKLASA, J. Concerning the substitution of arsenic acid for phosphoric acid in the nutrition of plants. (Abstract in *Expt. Sta. Rec.* 9: 1028, 1898.)

SWINGLE, D. B. Report. *Mont. Agr. Expt. Sta. Rpt., 1920:* 24–25, 1920.

—— Report. *Mont. Agr. Expt. Sta. Rpt., 1923:* 25–26, 1923.

——, and H. E. MORRIS. A preliminary report on the effects of arsenical compounds upon apple trees. *Phytopathology* 1: 79–93, 1911.

—— Arsenical injury through the bark of fruit trees. *Jour. Agr. Res.* 8: 283–318, 1917.

TALBERT, T. J., and W. L. TAYLOE. *Some results from feeding spray chemicals to albino rats.* Mo. Agr. Expt. Sta. Res. Bul. 183. 19 p. Columbia, Mo., 1933.

TRUOG, E., and A. M. MEYER. Improvements in the Deniges colorimetric method for phosphorus and arsenic. *Indus. and Eng. Chem., Analyt. Ed.* 1: 136, 1929.

VANDECAVEYE, S. C., G. M. HORNER, and C. M. KEATON. Unproductiveness of certain orchard soils as related to lead arsenate spray accumulation. *Soil Sci.* 42: 203–216, 1936.

WILLIAMS, K. T., and R. R. WHETSTONE. *Arsenic distribution in soils and its presence in certain plants.* U. S. Dept. Agr. Tech. Bul. 72. 20 p., Washington, D. C., 1940.

ZUCCARI, G. The presence of arsenic as a normal element of soil. (Abstract in *Expt. Sta. Rec.* 30: 321, 1914.)

Factors in the Behavior of Ground Water in a Ghyben-Herzberg System

CHESTER K. WENTWORTH[1]

INTRODUCTION

THE HYDROSTATIC RELATIONSHIP between fresh ground water and sea water along coasts and in many islands has been recognized for about 60 years, since the work of Badon Ghyben (1889) and of Herzberg (1901). It has been studied in various parts of the world but perhaps nowhere are there more data concerning it than in Hawaii. In the course of the Pacific war the occurrence of ground water on many islands has been of crucial importance and the concept of a Ghyben-Herzberg lens has become widely circulated.

Rain falling on the surface of an ideally permeable circular island in the ocean is in part absorbed into the ground. This water percolates downward and accumulates at the surface of the salt water at sea level. The fresh water builds up to a height above sea level determined by its amount and by the permeability of the island rock, and also presses downward until it extends about 40 times as far below sea level as it does above sea level. The upper surface of such a ground-water body can be shown to be a domed one, and the lower surface is deeply curved because of the ratio of 1 to 40. The fresh-water body thus approximates the form of a double convex lens, with the circular edge coinciding with the circular coast (Fig. 1). This is the Ghyben-Herzberg lens, and the model on which the theory rests. In many places, owing to differences in rock structure, only a portion or sector of the lens will be developed, but the principle applies equally well.

[1] Geologist, Board of Water Supply, Honolulu, Hawaii. Manuscript received February 6, 1947.

The Ghyben-Herzberg balance is not by any means universal along ocean coasts and one may presume that it is well exemplified along only a small fraction of continental coasts. Otherwise it would probably be better known. Its somewhat limited occurrence is due to the requirement of rocks within a certain range of permeability, sufficient rainfall, and lack of specialized structure in the rocks. The rock structure must in the main be fairly homogeneous and be isotropically permeable if a well-characterized Ghyben-Herzberg system is to develop.

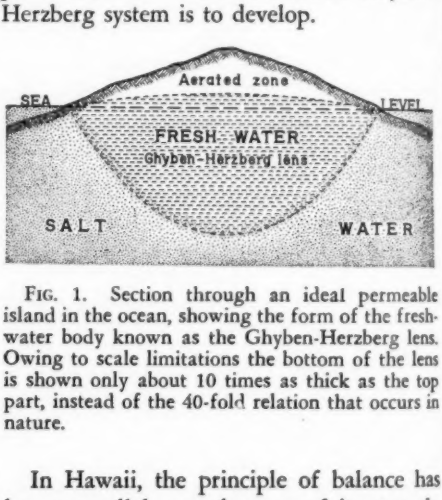


FIG. 1. Section through an ideal permeable island in the ocean, showing the form of the fresh-water body known as the Ghyben-Herzberg lens. Owing to scale limitations the bottom of the lens is shown only about 10 times as thick as the top part, instead of the 40-fold relation that occurs in nature.

In Hawaii, the principle of balance has become well known because of its remarkable development in the Honolulu–Pearl Harbor areas and in a few other localities on Oahu (Alexander, 1908; Andrews, 1909; Palmer, 1927: 17–20). It is not present or at least is scarcely demonstrable along about half of the windward coast because the rock is of low permeability and unsuitable structure. It is also much less developed on most of the other islands of Hawaii. Practical im-

portance of the lens is great because in it a much greater thickness of fresh or near-fresh water is accumulated at sea level than would otherwise be the case. In fact the fresh water is perched on salt water. Because of the wide extent of such possible perching, these basal water bodies lying in Ghyben-Herzberg balance are the largest ground water resources of the region.

In rocks not favorable for developing such a lens, there may be springs of fresh water at sea level. These springs are mostly small and unimportant and are occasioned by the cutting of the sea against the land, by an action such as that which produces valley-side springs. In Hawaii the basal water which is in Ghyben-Herzberg balance may, or may not, be in part artesian. Where a cap rock exists, the thickness of the lens is increased by its retardation; but the cap rock is not essential. The development of hydrostatic balance occurs even where the lighter water of the lens is somewhat brackish. Such a system may be of true Ghyben-Herzberg form even where the land water carries a considerable fraction of sea water. But for practical use only the more perfect systems where the upper water has less salt than corresponds to about 1 to 2 per cent of sea water are of interest. Salinity of the Honolulu city supply corresponds to approximately 1/400 sea water.

Often water supply systems are planned where there is some indication of fresh land water at the coast. Here it is supposed that only drilling or tunneling may be needed to secure a potable supply. Often such excavation after prolonged test may show that despite some degree of Ghyben-Herzberg functioning the resulting developed water is too saline for the proposed use. Or, the water may grow progressively more saline and show that the hydrostatic system is not sufficiently stable to stand the disturbance of even a moderate draft of water. Engineers and others who have accepted the principle are naturally disappointed and in turn question it after such adverse tests. But in the writer's view it is not surprising that the fresh-water lens in certain areas is either lacking or fails to meet the extremely severe test of yielding potable water continuously. Rather, it continues as one of the natural wonders that such systems as that at Honolulu and a few other places have been developed in course of geological time, in such perfection and with such ability to withstand modification through artificial development of the water. These systems are the exceptions rather than the rule.

Observations in various parts of Hawaii and a growing knowledge of basal water conditions on other Pacific islands permit some broad generalizations concerning the conditions essential to an effective Ghyben-Herzberg system. An attempt is made in this paper to outline the requisite conditions.

In the course of compiling this discussion, the manuscript has been read and criticized by Charles V. Theis, Arthur M. Piper, L. H. Herschler, and Gordon A. Macdonald, each of whom has made valuable suggestions. The writer is indebted particularly to the latter, with whom he has had many most profitable discussions on this and related problems over a period of years.

OUTLINE OF FACTORS

In outlining the factors affecting salinity, attention is first drawn to the fact that the Ghyben-Herzberg lens consists of a lighter liquid, floating on a heavier liquid and miscible with it. If the two liquids were not miscible, they could maintain their separate character and their common boundary indefinitely even without being restrained in a permeable aquifer. However, as they are miscible, if the permeable aquifer were not present the two liquids would become mixed and diffused in a short time so that the lighter lens would be destroyed. On the

other hand, if the rock at sea level is not permeable, there is no opportunity for a condition of hydraulic balance to become established. The fresh water cannot adjust itself to the salt water in relation to sea level and thus no Ghyben-Herzberg lens will be formed.

The first requisite is then a suitable degree of permeability. This must be small enough to prevent the general mixing which would destroy such a system and large enough to permit fresh water under the existing head differences to move against sea water. Only then can fresh water progressively displace salt water in forming a Ghyben-Herzberg lens. It will be seen presently that the permeability which proves effective is relative to other factors, and can be better discussed after these have been listed.

Next to suitable permeability is an infiltration of rainfall of sufficient amount and continuity to build and maintain a fresh basal ground-water body about a foot or more above sea level. According to the rainfall and recharge, there is built a surcharge above sea level adequate to discharge the average daily or annual amount to the periphery of the island. The maintenance of this surcharge causes the downward accumulation of fresh water until an approximate Ghyben-Herzberg lens is produced. The miscibility of the fresh and salt water tends to destroy the lens or the sharpness of its margin. The rate of addition of fresh water must be sufficient to overcome this tendency.

The third requirement is a sufficiently small fluctuation in both ground-water heads and in sea-water levels to minimize the effects of mixing and the spread of the zone of mixing through reversal of movement. Fluctuations in ground-water head are due to seasonal and other variations in rainfall and recharge. Chief changes in sea level that we need to consider are those due to tides. It seems fairly certain that small islands, which with tidal range of 2 feet show moderate stability of the Ghyben-Herzberg lens, if subjected to a 15- or 20-foot tidal range would show serious disturbances of the lens.

It is difficult to give any categorical specifications, but the best-known Ghyben-Herzberg water bodies in Hawaii do not have seasonal or annual fluctuations of water table exceeding perhaps one fifth of the total height of water table above sea level. It seems likely that any annual change such as half or two thirds of the mean value would tend to prevent growth of a lens from which any potable water could be taken. Both in their accomplishment and also in their effect on water quality, the amplitude of such fluctuations is obviously related not only to the infiltration changes but also to the permeability.

A fourth factor, and in some ways the most important of all, is that of comparative uniformity and regularity of permeability, and freedom from large and long openings crossing the boundary between fresh and salt water. Much of the effectiveness of the Ghyben-Herzberg mechanism depends on the maintaining of a fairly smooth and orderly boundary between the two liquids, as closely analogous as possible to the mathematically definable boundary between immiscible liquids. It is fairly evident that the actual condition is somewhat remote from this and, with fluctuating directions of movement, that existing large fissures or tubes must carry long filaments of one sort of water into the realm of the other, and vice versa. Such conditions seem to explain the observed vagaries in the composition of water from different wells in the same district and even at the same depth. Despite such irregular and fluctuating interpenetrations, a broad regularity of boundary is shown in the more stable Ghyben-Herzberg systems such as those of Oahu. Certainly if changing heads tend to move the salt–fresh

boundary up and down alternately, any large openings which cross the boundary will be much more destructive in promoting interpenetration of one kind of water by the other than small openings. It appears clear that heterogeneous permeability will be more likely to produce an irregular and disorderly boundary than a homogeneous or regular permeability.

A fifth factor of importance is the effectiveness of a cap rock along the coast. Such a barrier not only promotes the building of higher heads of fresh water but indeed creates a condition somewhat akin to a U-tube so that at their two upper surfaces the fresh- and salt-water bodies are effectively separated. The first and most advanced intermixing of salt and fresh water would normally take place at the coastal margin. Here changing head differences would be exerted across the shortest distances between fresh ground water and free sea water. Evidently a barrier along the coast would have marked protective value. In the Honolulu area the thickness and width of the cap rock are such as to interpose a distance of several thousands of feet in most places between the water table and free sea water, and this barrier is of tremendous importance.

The factors mentioned above are, in summary: (1) suitable permeability, (2) adequate infiltration, (3) limited fluctuation, (4) regularity of permeability, (5) an effective cap rock. Some aspects of their interrelationships will now be discussed.

PERMEABILITY

It would be difficult to over-emphasize the importance of time in the inter-relationship of the several factors. The first factor, permeability, is of course a rate of discharge through a specified cross-section, and infiltration is expressed as an amount per unit of time and per unit of area. It is the lag in the dissipation of infiltrated water through permeable rocks which causes the initial accumulation of ground water and determines the ultimate head at which balance between gain and loss will be reached. In general, on islands of similar geometrical form, infiltration proceeds through areas that are proportional to the squares of linear dimensions, whereas for the same heads, the areas through which discharge to the sea takes place are proportional to perimeters, hence to the first powers of linear dimensions. Hence derives the tendency to build higher water tables on larger islands, thus restoring some degree of equality with this second dimension. It is also true that larger islands have longer radii and greater likelihood of continuous discharge even with discontinuous rainfall and infiltration.

Permeability that is too great (relative to infiltration and other factors) will result in a water table so low that no permanent pressure against salt water will be maintained and no permanent Ghyben-Herzberg lens will exist. On the other hand, if permeability is too low the amount of water infiltrated will be small, and the exerting of a systematic pressure against the sea water is less likely to be established. With the higher water tables due to less permeable rocks there is less likelihood that rocks of reasonably uniform permeability will extend to the depth below sea level requisite for a functional system. Moreover, even if balance exists, the lesser permeability precludes the detectable response by which we might recognize it. Thus on various less observable grounds the Ghyben-Herzberg condition vanishes also with reduced permeability.

It is possible, too, that in some islands the rock near sea level and slightly below at the coast is less permeable than the general mass below sea level and farther inland. Such difference within a favorable range of magnitudes would promote the Ghyben-Herzberg condition.

INFILTRATION

It is hardly practicable to suggest a numerical definition of adequate infiltration, but some limiting data may be offered. On some of the larger islands of Hawaii, where the discharge through the shore perimeter in some sections reaches values of 5, 10, or even 20 million gallons daily per shore-line mile, with other conditions favorable, Ghyben-Herzberg conditions are conspicuous and stable. These conditions imply some intake area with annual rainfall of 100 inches or more. In many other areas of Hawaii, on leeward coasts or on smaller islands, where rainfall is mostly under 50 inches and ground-water discharge is 1, ½, or 1/10 M.G.D. per shore-line mile, the Ghyben-Herzberg condition is either missing or nondemonstrable on the scale of practical water-supply operations. However, it should be remembered that under wartime or expeditionary conditions a vestigial fresh-water lens may be of great temporary value even though it may fail on continuous mechanized development.

The size of the island is important here; on an island 2 miles in diameter the discharged ground-water fraction required to equal 1.0 M.G.D. per shore-line mile is 42 inches over the area, whereas on one 10 miles in diameter 42 inches over the area will give 5 M.G.D. per shore-line mile. From experience in Hawaii the latter would quite likely have the Ghyben-Herzberg condition; the former very likely would not, unless the permeability or cap rock were especially favorable.

It may now be practicable to say that the required permeability assumed to be fairly homogeneous throughout the whole thickness is such as will require the water table to build up 2 to 10 feet or more and remain at nearly constant levels perennially. With lesser heads some degree of concentration of fresh water may be found but it is less likely to be stable against mechanized exploitation.

FLUCTUATION

The permissible annual fluctuation so far as we can estimate at present is somewhat less than one half of the mean water-table head, and in most cases less than one fourth of that head. No data are at hand, for any system of the magnitude of that of Honolulu, in which greater fractions of fluctuation are known. For systems with head of 5 feet or less it seems indicated that fluctuation from 2.5 to 7.5 feet of head would be fatal to useful Ghyben-Herzberg stability. No data are available to determine what ratio of short-term fluctuations might be tolerable, but naturally the tolerable limiting amplitude would be lower than for the longer term ones, and in the nature of the case they are materially less.

REGULARITY OF PERMEABILITY

By regularity of permeability we mean homogeneity of distribution and sizes of interconnected openings. A formation consisting of well-sorted sand or gravel would throughout its mass have regular permeability. A formation consisting of moderately permeable material but broken by large, irregularly spaced fissures or caverns would have irregular permeability. The adverse effect of irregular permeability would lie in introducing large and changeable irregularity of pattern in the three-dimensional network of surfaces of equal pressure and hence of lines of flow, of velocities, and of salinities. It is evident that in formations permeable enough to meet the Ghyben-Herzberg requirement, large irregularities will promote intermixing and tend to effacement of the zone of balance, which without frictional retardation can only be stable between immiscible liquids. In a sense, large openings of such length and direction as to lead across

the zone of mixing are to be regarded as short circuits which would produce potential disturbance analogous to that in an electrical network. Moreover, the movement of saline water toward fresh, or vice versa, taking place during any phase would leave residues of great importance. It therefore appears that, increasingly, irregularity of permeability would tend strongly toward effacement of the salt-water–fresh-water contact on which the Ghyben-Herzberg lens depends, just as would increase of general permeability.

It appears that this variation in permeability, with some large openings going outside the favorable range of permeability, may be a very large factor in explaining the great differences in the Ghyben-Herzberg conditions on different coral limestone islands, or on different parts of the same island. Not only initial differences due to structure of the calcareous accumulation, but also fissures developed near sea level by the action of fresh water probably are important here. Such an interpretation has been suggested by the writer's observations in the Marianas during early stages of military operations there and has also been emphasized by others.[2]

CAP ROCK

It is not difficult to show why an effective cap rock is so very significant in permitting the growth of some of the larger Ghyben-Herzberg lenses. It is an essential part of that theory that in a steady condition of dynamic balance, with the thickness of the lens neither increasing nor decreasing, lines may be drawn from various points of the top of the lens (the water table) passing downward and outward in a wide curve to emerge in the ocean surface, along which hydrostatic pressures are in balance. If the position of the water table is changed by fluctuations of recharge or of loss, movement will tend to take place along these lines in accordance with the size of openings and length of path. It is evident that those paths

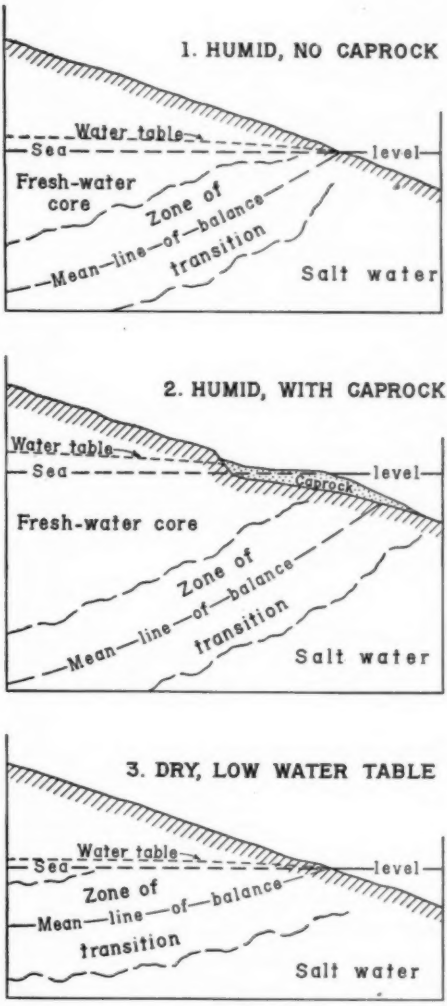


FIG. 2. Schematic sections through the margin of a Ghyben-Herzberg lens, under the three conditions indicated in the text. For convenience in drawing, the mean line of balance is based on a ratio of 10 : 1, rather than the true ratio of approximately 40 : 1.

[2] Piper, Arthur M. Letter dated December 5, 1946.

nearer to the shore line are much the shorter and that under fluctuating conditions of unbalance, water movement in larger openings across the zone of contact would take place here more rapidly than elsewhere (see Fig. 2). Along a shore unprotected by a cap rock, the thin edge of the Ghyben-Herzberg lens would be especially vulnerable to disturbance or destruction during marked fluctuations. There, particularly, the adverse effect of large fissures or other irregularity of permeability is certain to be great.

From these considerations, the value of a cap rock as a barrier between fresh and salt water is readily seen. As stated elsewhere, the interposition of the cap rock between fresh and salt water in effect completes the physical pattern of a U-tube. It tends to raise the head of basal water and to truncate and thicken its shore margin. This barrier has the result of eliminating the thin edge of the lens, with its dangerous sensitivity to plus and minus fluctuations. It should not be overlooked, also, that in most places the Ghyben-Herzberg condition is first recognized and is most useful in the shore zone where the water is most accessible and often most needed. It is possible that more complete and more extensive exploration will demonstrate the interior existence of Ghyben-Herzberg lenses in some islands where the condition is not well shown at the shore; such discoveries would confirm the contentions of this paper.

PARTS OF THE LENS

In the preceding sections, the five factors controlling the establishment and growth of the Ghyben-Herzberg lens have been discussed. Attention is now directed to the parts of the lens and to the nature of its lower boundary. It has been accepted that the lower surface of the lens is a zone of transition from fresh to salt water, and that since the two liquids are miscible the zone will have thickness. The perfect condition of a sharp boundary can only obtain with immiscible liquids. If the permeability is too great for the amount of infiltration, or if there is great irregularity of permeability, the mixing and mutual interpenetration of the two waters will be promoted and the zone of transition will be thickened. Such mixing may go so far that no part of the lens is free from salt contamination.

GROWTH OF DIFFUSION ZONE

Another effect, that of fluctuation or alternate movements of the zone of transition, may not be so readily discerned. With immiscible liquids and no matrix such as rock, the contact surface would move up or down according to relative pressures and with little or no deformation. However, in rock with miscible liquids, the migration of the zone downward into rock formerly filled with salt water would first involve driving out some of the salt water. But it would also result in assimilation of some of the salt water remaining longer in smaller openings. If such a process continued, the water composition at any one place would tend to approximate more and more that of the advancing water and retain less and less of the quality of the water originally displaced. However, there would commonly, after any short time, be some residue of the displaced water. If we assume that at any given time the local composition is a function of the compositions of the two waters and of the time during which Water A has moved into the realm of Water B, a process analogous to the exponential law of rinsing, some interesting consequences appear. If, for example, the two waters have an initially sharp boundary, and that boundary is moved under hydrostatic changes of sign from one realm to the other, in equal amounts successively, the most immediate effect is the spreading of the boundary so that it is no longer sharp but assumes a graded transition form.

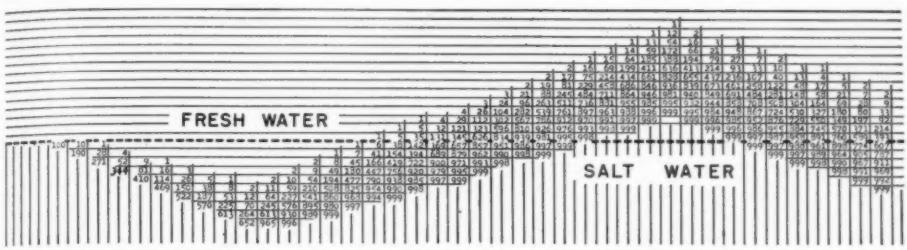


FIG. 3. A numerical model showing growth of the transition zone under the assumption of progressive rinsing, analogous to the exponential theory of rinsing. The unmodified fresh and salt waters are shown by the respective horizontal and vertical hatching. The transition zone is shown by the growing band of figures, the successive values being parts per thousand of salt water.

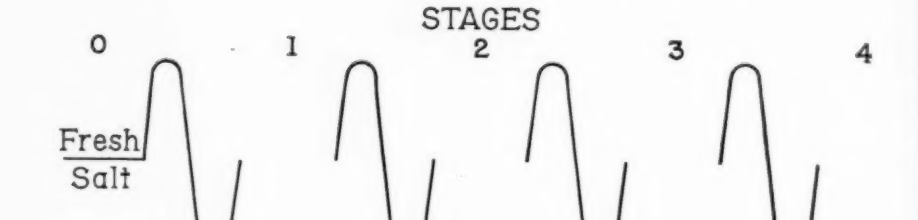
Figure 3 is a numerical model showing the effect of moving the junction between two types of water to and fro in a permeable medium having some storage capacity. At the beginning of the test period, the junction is assumed to be sharp, as shown by the respective patterns (Fig. 3). Each successive column of figures represents the composition in successive, equal periods of time. The fresh water is assumed to move by 10 successive units of motion against the salt water, thence to retreat by 20 units to a position 10 units on the other, or fresh, side of the initial line of balance, and finally to return by 10 units to that line and thus complete one full cycle. With each unit of movement, the water in a given position is assumed to be made up of 9 parts of oncoming water and 1 part of residual water. It is immaterial for the discussion whether the residue be assumed as 10 per cent or some other figure.

The figures represent parts per thousand of salt water. Above the transition zone all the water is fresh, taken as zero parts. Below it, the water is of sea-water composition, taken as 1,000 parts. A certain raggedness appears at the margins, owing to limiting the calculations to the nearest thousandth. So far as practicable the accumulation of values of the next digit has been anticipated in computing the marginal figures.

It is evident from Figure 3 that changes take place both at the advancing margin and at the following margin. The composition at the advancing margin is changed toward that of the water being invaded, and that change migrates into the advancing front. The same direction of change is reflected through the zone, and the compositions in the following margin also change toward that of the water being invaded. The rates of these changes are determined by the existing gradient of composition at various points in the transition zone.

After the first reversal, the form of the composition diagram becomes nearly symmetrical (Fig. 4). With continued fluctuation the transition zone becomes progressively wider and the rate of change of composition within it is slower. The fresh water is more deeply penetrated by a graded fringe of saline composition and the salt water more deeply penetrated by a graded fringe of freshened water. This effect is indicated in the progressive flattening of the transition curves of Figure 4, as well as by the march of the figures in Figure 3.

It is possible that with a symmetrical series of fluctuations a limit of width would in time be reached in a regularly permeable aquifer. However, in any natural aquifer and particularly with unsymmetrical fluctuations and with movement under new head



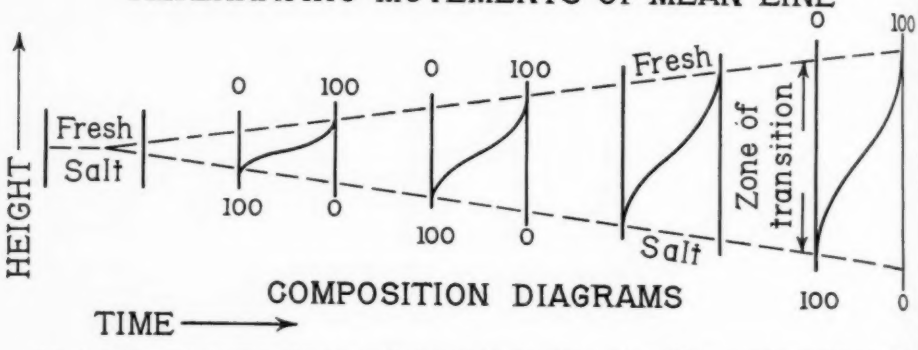


FIG. 4. Schematic diagram showing widening of the transition zone with successive cycles of alternate invasion of one type of water by the other. The lower part shows five composition diagrams, commencing with the sharp boundary at the left. The general sigmoid form of the composition line may be verified by plotting the figures given in the right-hand column of Figure 3.

differences through larger openings in different zones, we cannot doubt that there will be slow and persistent growth in the width of the zone because of this rinsing effect. Thus we suppose that, setting any given limits at the two margins, the thickness of the transition zone will become progressively greater as alternations are repeated, or as the movement assumes greater amplitude.

The composition diagram developed on this assumption of rinsing is a symmetrical curve starting as an asymptote to the zero line of salinity, passing through an inflexion at the 50 per cent point, and terminating as an asymptote to the line of 100 per cent salinity of sea water. After any series of complete cycles the zone has widened, but the line of equivalent density or balance is found in the position formerly occupied by the initial sharp boundary.

REVERSIBILITY

We seem now able to resolve the often discussed problem of reversibility of the process of saline encroachment. This has vexed many people in Hawaii and seems to be clarified by the above discussion. From that line of reasoning, we may say at once that if we consider the position of the 50 per cent line, or the equivalent position of total salt against total fresh water, the process of saline encroachment does appear to be completely reversible. After a period of reversed movement equal in duration and intensity to the earlier saline encroachment, assuming each movement completed, we

would expect to find the middle of the zone of transition or diffusion at the same level it occupied initially. However, we are only theoretically interested in the middle of this zone; for practical purposes our interest in an operating Ghyben-Herzberg system is concentrated on that fringe nearest the fresh water, where the salinity is equivalent to the order of 1 per cent of sea water or less. It appears that any movement of the zone of transition causes it to widen. Thus the center of the zone may return to a former position after equal and alternate movements, but the near edge of the zone, judged by any defined standard, because of the previously stated principle of widening will not retract as readily as it advances.

Thus it appears that in the practical sense, in relation to exploitation of potable or agriculturally useful water, the encroachment of saline water, under the natural plus artificial and somewhat aggravated fluctuations, will take place more readily than the reverse process of elimination under a conservation program. Thus there is an element of irreversibility, despite the difficulty which various workers, including the present writer, have had in seeing why the salt water could not be driven back by an equal period of reversed movement. Some have postulated trapping of salt water in pockets. It must, however, be pointed out that in a hydraulic system where water may move either way, trapping is not restricted to pocketing against the direction of gravity but could equally well work the other way with reverse direction of water movement. It is concluded here that no special theory of trapping, especially trapping in one direction, is needed, nor is any theory of directionality required. The condition seems fully explained by the concept of symmetrical thickening, due to rinsing, plus the fixing of practical interest in a position on the near, or upper, side of the zone of transition.

DIFFERENCES IN SYSTEMS

We need now to offer acceptable explanations of the differing qualities of water in various systems. It has been found in various places in Hawaii that the main part of some of the larger Ghyben-Herzberg systems may for many years furnish water of surprising constancy of salinity. There are three most evident sources of sodium chloride: (1) from normal rock weathering, (2) from salts left on the land from salt spray or from more saline irrigation waters, (3) from admixture in the aquifer with intruding sea water.

We are well acquainted with marked increases due to the third factor; there is an equal amount of evidence on aquifers which over a period of many years, and even with considerable reduction of head and increase of draft, continue not to be affected by (3) but represent a stable and not wholly defined combination of (1) and (2). This is true of some aquifers where the draft of water is from points several hundred feet below sea level. Obviously such points are in a part of the Ghyben-Herzberg lens that is not yet affected by saline encroachment (from 3) and cannot be a part of the transition zone. That in course of time, through thickening of the zone, they might become so is, unfortunately, one of the practical lessons we learn.

On the other hand, we find aquifers in which the Ghyben-Herzberg lens at any level, from the top downward, yields water of high salinity, often increasing markedly with draft, and appears to be deriving it from normal and induced admixture of sea water. In such places we can only conclude that the whole lens is a part of the zone of transition. It appears therefore that while some lenses have a considerable fraction of water not affected by the adjacent salt water, others do not. For convenience we may call the upper part the fresh-water core.

MAINTAINING THE CORE

The fresh-water core is a unit through which passes annually the amount of water added to the water table. Some of this water passes down the slope of the water table to escape near the coast, but there is no question that there is considerable deeper circulation. However, except for the migration of the zone of transition with fluctuations of rainfall and draft, and the effect of a few large openings with unbalanced pressures, the water does not move through the transition zone. More properly we can assume that the water in the fresh core circulates past the upper fringe of the transition zone. Presumably this circulation in some lenses is sufficiently active to offer considerable resistance to the thickening of the transition zone. This would operate by rinsing away any slight increases in salinity that might persist if the invading fringe of saline composition were penetrating a truly static body.

It appears that in some of the thicker and more functional Ghyben-Herzberg lenses, the transition zone has not become thick enough to reach the top of the lens. The circulation in this upper fresh-water core is active enough to provide an adequate rinsing action against the upper fringe of the transition zone. Hence the integrity and water quality of the fresh-water core are well maintained. In other lenses, usually much thinner and perhaps developed under less favorable conditions, the transition zone has either thickened to encompass the whole thickness of the lens or perhaps has always had some such thickness. Here there is no fresh-water core, at least not at the coast or where exploration has penetrated.

Experience in finding small amounts of water of low salinity at the very top of such water bodies by no means invalidates the distinctions set forth above. Undoubtedly in wet weather a certain amount of rain water would move down the slope of the water table with only slight mixing with the prevailing ground water; such would be the source of a fresh-water layer, but the layer would be insufficient in amount. Not uncommonly water bodies which will yield fresh water in small samples are found on drilling and pumping to yield only water of considerably higher salinity. For this reason preliminary or bailed samples sometimes lead to hopes that are later not realized.

It is not intended here to treat the various complexities of water development from the Ghyben-Herzberg lens, but the few elements which enter into the problem may be mentioned. We start by emphasizing that the lens is a storage body or gland through which water is moving, and that under balanced conditions the inflow and outflow are equal in amount.

Because the upper surface slopes toward the ocean and the rocks are permeable, there is a steady loss proportional to the head differences through various openings, whose locations are usually not known in detail. So long as this head is maintained these openings, if not plugged, will discharge the same amount of water. If water is to be taken by man, the head must be lowered until the loss from various openings has been reduced by the amount taken artificially. The lowering of head makes water temporarily available from storage at the upper surface; if we follow the Ghyben-Herzberg principle we cannot doubt that in due course the bottom of the lens must shrink to reach a new equilibrium. This will yield, over a long period, very large amounts of water. This condition appears to explain the remarkable stability against draft which is shown by some large systems (Wentworth: 1942).

EFFECT OF DRAFT ON QUALITY

We have seen that the water of the lens is in motion, toward points of outflow, which in hydraulic terms are called sinks. When a well or shaft is dug and water is

taken therefrom, this becomes a new point of outflow, or sink. The quality of the water at any given point is determined by the rates and amounts of flow induced under hydraulic conditions from the several accessible sources. Availability of water from those sources depends on the sizes and number of openings connecting them with the sampling point and on the proportionate hydraulic flow induced by draft at the sampling point. When the draft from a well is applied to the pre-existing flow pattern, that pattern is changed and the well competes for water against the other flow lines. The quality of water drawn depends on the flow pattern set up under the new conditions and on the compositions of the several waters available.

The larger the intake surface (as in a long tunnel rather than a small well), the smaller the drawdown required and the smaller the disturbance of pre-existing flow lines required to get the water. In such case the salinity of the water drawn will probably be less modified from that sampled from the aquifer under the original flow conditions. Particularly, the smaller the drawdown, the smaller the likelihood of inducing flow from lower parts of the lens, which may be more saline.

In general, near the coast, the salinity of water taken from a well increases with increase of depth and with increase of draft. It also is greater at low regional heads than at high, and, as stated above, is greater at high drawdown than at low. Two wells of similar depth and location often show quite marked differences, owing to different, though often unknown, openings in the formations they penetrate. Occasionally wells or shafts are dug which encounter openings that are thought to run inland and in which the water becomes less saline as draft is increased; the reverse is far the more common situation. These exceptions do not invalidate any of the recognized principles; they merely emphasize the complexity of the hydrologic conditions involved, and our inability in most cases to make specific predictions.

A Ghyben-Herzberg lens is of great economic value when it has a fresh-water core of such size and stability as to permit the desired draft of fresh water and yet continue to maintain the freshness of the core. Where these conditions of stability exist and can be maintained, the amounts of water which can be taken out and the capacity of the system to sustain short period overdraft are truly astonishing. A great deal of exploration and usually much full-scale operation will be required in most such systems before the safe capacity or other conditions of operation can be determined. The chief requisite in any given case is a body of data that covers a sufficient range of facts and of time, together with recognition of the principles involved. The present paper is offered as an elementary formulation of those principles as they appear at present.

SUMMARY

The Ghyben-Herzberg lens is essentially a gland, into which water moves from rainfall and out of which it moves through natural leaks and artificial discharge. Because of contact with salt water, with which it can mix, the lens of fresh water is in an intermediate condition of equilibrium. To survive, it must not be stagnant; water must move through it. It can be destroyed by too little source water or by too rapid escape of water. In rocks that are too impermeable the dynamic equilibrium may not be set up. The formation and survival of such a lens in a given place depends on the values and mutual relations of the factors of permeability, rainfall, fluctuations in level, regularity of permeability, and presence or absence of a cap rock. Change of one of these conditions, such as fluctuation, may change the balance on which such a lens depends.

REFERENCES

ALEXANDER, W. D. Letter to the editor. *Pacific Commercial Advertiser* (Honolulu), Oct. 9, 1908.

ANDREWS, CARL B. *Structure of the southeastern portion of the island of Oahu, Hawaiian Islands.* 19 p., 18 fig. [Thesis, Rose Polytechnic Institute, 1909.]

BADON GHYBEN, W. Nota in verband met de voorgenomen put boring nabij Amsterdam. *K. Inst. Ingen. Tijdschr., 1888–89:* 8–22, 2 pl. The Hague, 1889.

BROWN, J. S. *A study of coastal ground water, with special reference to Connecticut.* 101 p., 20 pl., 7 fig. U. S. Geol. Survey Water-Supply Paper 537, Washington, D. C., 1925.

HERZBERG, BAURAT. Die wasserversorgung einiger Nordseebader. *Jour. Gasbeleuchtung und Wasserversorgung.*, Jahrg. 44. Munich, 1901.

PALMER, H. S. *The geology of the Honolulu artesian system.* Rpt., Honolulu Sewer and Water Commission, supplement. 68 p., 21 fig. Honolulu, 1927.

STEARNS, H. T., and K. N. VAKSVIK. *Geology and ground-water resources of the island of Oahu, Hawaii.* 479 p., 33 pl., 34 fig. Ter. of Hawaii Div. Hydrog., Bul. 1. Honolulu, 1935.

WENTWORTH, CHESTER K. Storage consequences of the Ghyben-Herzberg theory. *Amer. Geophys. Union Trans.* 23: 683–693, 1942.

——— *The specific gravity of sea water and the Ghyben-Herzberg ratio at Honolulu.* 24 p., 3 fig. Hawaii Univ. Occas. Paper 39. Honolulu, 1939.

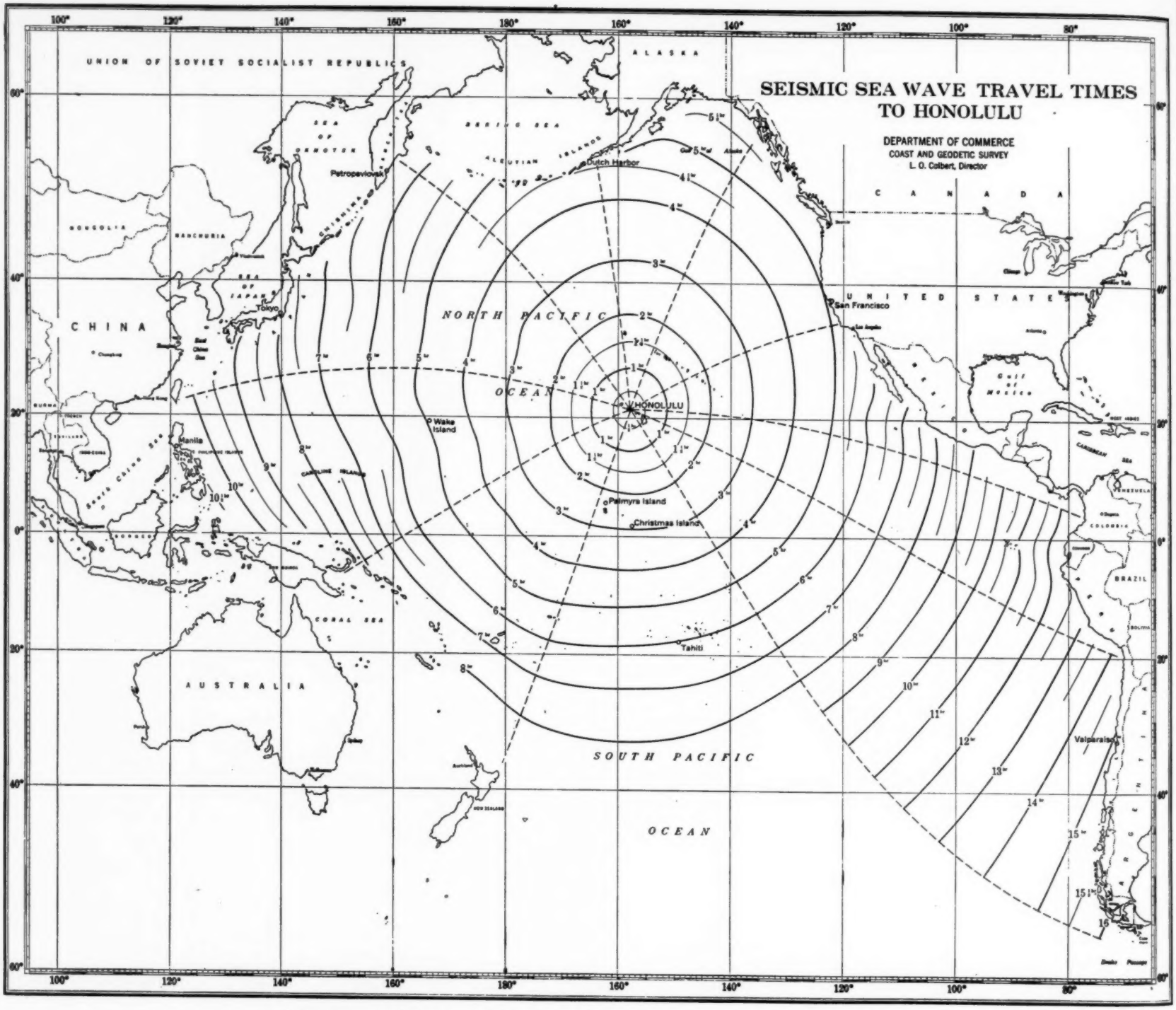


FIG. 1. Chart published by the U. S. Coast and Geodetic Survey showing seismic sea wave travel times to Honolulu is here reproduced on a small scale with the omission of some detail. (To accompany "Travel Times of Seismic Sea Waves to Honolulu," by Bernard D. Zetler, PACIFIC SCIENCE, vol. 1, July, 1947.)

Travel Times of Seismic Sea Waves to Honolulu

BERNARD D. ZETLER[1]

THE SEISMIC SEA WAVE which struck the Hawaiian Islands on April 1, 1946, has again focused attention on the necessity for adequate protective measures against similar disasters in the future. The problem is obviously complex, involving rapid location of the epicenter, the detection of the sea wave as it moves toward the Hawaiian Islands, a quick method of determining the time the wave will reach the islands, and finally an adequate means of providing security for people and property. The purpose of this study was the preparation of a chart of the Pacific Ocean which would show the travel time to Honolulu of a seismic sea wave from the plotted position of an earthquake epicenter (see Fig. 1, insert sheet). Given the time of the disturbance, the arrival time of the wave at Honolulu becomes immediately available.

Oceanographers have long accepted the concept that the velocity of a seismic sea wave is a function of the depth of water and they have expressed it mathematically as $v = \sqrt{gd}$, where v is the velocity of the wave, g the acceleration of gravity, and d the depth of the water. However, this formula for velocity has been considered by some authorities to be a rough approximation; it was believed that the actual velocity would always be somewhat slower.

The results of the computations made in the course of the study by Green (1946) created more confidence in the accuracy of travel times computed by means of this formula. These computations were not influenced by the recorded arrival times; the times to several of the more distant places were computed before it was known that the sea wave had been recorded on the gages. Table 1 of that report lists 12 places whose distances from the epicenter vary from 1,610 to 8,066 statute miles. A comparison of observed with computed travel times to these places shows an average variation of 1.2 per cent, which is not consistently in one direction.

It was decided that the procedures used in the above project could be adopted in the preparation of a chart which would show the travel time of any seismic sea wave to Honolulu. A series of ½-hour curves would be drawn on the chart such that each would represent the length of time a sea wave would take to reach Honolulu from an epicenter at any point on the curve.

Points to be used as epicenters of sea waves were selected in various directions from Honolulu, and travel times were computed, using soundings from large-scale charts, along arcs of great circles between these points and Honolulu. Half-hour intervals were plotted along each arc with numerical time values increasing with distance from Honolulu. The time curves were drawn by connecting the respective ½-hour points.

Although observed travel times were available for a number of sea waves which had previously been recorded on the Honolulu tide gage, it was considered desirable to use computed rather than observed data in the construction of the chart. However, the positions of the epicenters of recorded waves were included among the points from which travel times were computed in order to make available a comparison of observed and computed travel times (see Table 1).

In preparing the time data along any particular path, a great circle course between

[1] Mathematician, U. S. Coast and Geodetic Survey, Washington, D. C. Manuscript received March 17, 1947.

the epicenter and the entrance to Honolulu Harbor was plotted on a chart of the Pacific Ocean. The path was transferred to larger scale nautical charts and then divided into sections of 120 nautical miles each, except when rapid changes in depth required sections of shorter length. The average depth in each section was taken and the time required to pass over it was computed as follows:

Let d represent the mean depth, in fathoms, of the 120-mile section and t the travel time of the sea wave over that section.

Since $v = \sqrt{gd} = 8.23\ \sqrt{d}$ nautical miles per hour, $t = 120/8.23\ \sqrt{d} = 14.58/\sqrt{d}$ hours.

The times thus computed were added cumulatively, increasing with distance from Honolulu, and the ½-hour points were determined by interpolation.

The dividing of a path into small sections increases the precision of the determinations over those which are obtained by using a mean depth over a whole distance. The 120-mile points were usually 0.25 to 0.35 hour apart, thus allowing for reliable interpolation of ½-hour points which would have been impossible were the path to be considered as a whole.

When a great circle course for a seismic sea wave is first laid off on large-scale charts, there are several details to be considered. If the path crosses a large unit of land, the portion of the wave front which reaches Honolulu will have to go around that land. Because the part of the wave front in deeper water will advance more rapidly, the path is considered the combination of arcs of two great circles joined in the deep water off the coast. If the path of a wave involves crossing a large section of shoal water, then the time of the wave front which diverges somewhat from the great circle course, but which travels over a deeper course, must be considered. An excellent example of the latter was found in the computation of the travel time of the wave from the Aleutian Trench on April 1, 1946, to Sitka, Alaska. The travel time along a great circle course, through shoal water most of the way, was computed as about 7 hours. By considering a path going to the southeast for about 90 miles and then moving along a great circle course from that point to Sitka, the time was calculated to be about 3 hours, which was in almost perfect agreement with the observed time.

The latter example is an extreme case. More frequently there was found a condition in which part of a great circle course covered an area less deep than that covered by an adjacent path. Despite the additional distance covered in diverging from a great circle course to get into deeper water, the total travel time may be less than that along the original great circle path. Shallow areas of this type caused irregularities in the time curves and necessitated the computation of additional paths and the consideration of the bathymetric pattern.

The problem of how to treat the computation of the travel time of a wave whose path lies in a deep channel with comparatively shallow water on both sides is a troublesome one. If the formula were followed rigorously in such a case, the front of the wave would gradually have to become more and more pointed as the wave moved forward, the shallow water on either side slowing down that portion of the wave front passing over it. The concept of such a pointed wave front did not seem reasonable, and the velocity was computed as just slightly faster than that over the shallow area. The observed travel times from several epicenters lying in deep channels were found to compare favorably with the times thus computed.

Some of the epicenters used in comparing observed with computed travel times were found to plot on land near ocean deeps. There have been some differences of opinion among seismologists whether the true epi-

central positions are on or off shore. The method used in this study necessitated a given depth of water to make a computation possible, and therefore the times were computed to the ocean deeps which are near the plotted epicenters. The comparison of observed and computed travel times would seem to indicate that this procedure is reasonable.

Three seismic sea waves which originated near the Japanese island of Honshu have been recorded on the tide record at Honolulu. The observed travel times exceed the computed times by 14, 23, and 49 minutes. The first two differences are sizable but not necessarily serious. There are several factors which can contribute to a small consistent variation. Accurate computations of travel time require adequate and reliable soundings. Some areas in the Pacific are inadequately surveyed, and the accuracy of some soundings in other areas is questionable. For the 120-mile travel path sections which contain large variations in depth, the procedure was to use a mean depth after rejecting occasional extremely shallow depths. This technique and the resulting mean depths are somewhat subjective and could lead to small inaccuracies in travel time.

The seismic disturbance off the south coast of Honshu on December 7, 1944, created a sea wave which arrived at Honolulu 9 hours and 9 minutes later, whereas the computed travel time for the path is 8 hours and 20 minutes. The epicenter of the December 20, 1946, sea wave is approximately 170 nautical miles west of the 1944 epicenter, the water between the two is relatively shallow, and great circle paths from the two to Honolulu would virtually coincide. The difference of only 3 minutes between the observed travel times cannot be explained by some of the difficulties mentioned above. It seems probable that some of the 49-minute difference must be attributed to tide gage operation, tide record interpretation, the seismological determination of epicenter, or a combination of these factors.

A serious misinterpretation of a tide marigram can take place if the waves are small in amplitude. The first wave is usually smaller than those immediately following it and may not be recognizable because of the seiche. Therefore a time of arrival which appears to be definite may refer to the second wave rather than the first. With an observed travel time greater than its true value, the time difference, computed minus observed, is large negatively.

Besides giving the travel time of a seismic sea wave from an epicenter, the chart may also be used in conjunction with apparatus which detects the sea wave as it moves toward the Hawaiian Islands. Midway Island, for example, lies approximately on a great circle arc between Honshu and Honolulu. If a wave were received at Midway from an epicenter near Honshu, a warning could be sent to Honolulu. The travel time difference between Midway and Honolulu of about 2 hours and 50 minutes is readily obtained from the chart. The necessary condition for using the chart in this fashion is that the outpost lie close to the great circle course from the epicenter to Honolulu. There are a number of other islands in the Pacific Ocean whose positions make possible their use as detector outposts for waves from other directions.

Travel time to other places in the Hawaiian Islands can be estimated with the aid of the time curves near the islands. For example, a seismic sea wave originating near Chile would reach Hilo about a half-hour before it reached Honolulu, but a sea wave from southeast Alaska would arrive at both places at approximately the same time.

Table 1 gives the geographic position of epicenter, the Greenwich time of the seismic disturbance, the location of the gage which recorded the receipt of the seismic sea wave

TABLE 1

COMPARISON OF OBSERVED AND COMPUTED TRAVEL TIMES OF SEISMIC SEA WAVES

(Mean variation of computed travel times with respect to observed times = 2.3 per cent.)

EARTHQUAKE							LOCATION OF TIDE GAGE	OBSERVED TRAVEL TIME	TIME DIFFERENCE (COMPUTED MINUS OBSERVED)
Epicenter			Greenwich Time						
Near	Lat.	Long.	Year	Month	Day	Hour			
	deg.	deg.				h. m.		h. m.	min.
Colombia	1 N.	80 W.	1906	Jan.	31	15 33	Honolulu	12 57	—27
Chile	33 S.	72 W.	1906	Aug.	17	00 41	Honolulu	15 12	— 2
Kermadec Is.	29.2 S.	177.0 W.	1917	May	1	18 27	Honolulu	8 01	— 6
Kuril Is.	46.5 N.	151.4 E.	1918	Sept.	7	17 16	Honolulu	6 36	+ 4
Tonga Is.	21.2 S.	172.5 W.	1919	April	30	07 17	Honolulu	6 36	— 4
Chile	29.0 S.	71.0 W.	1922	Nov.	11	04 32	Honolulu	14 58	+ 2
Kamchatka	54.0 N.	161.0 E.	1923	Feb.	3	16 02	Honolulu	6 18	+ 6
Kamchatka	55.7 N.	162.5 E.	1923	April	13	15 31	Honolulu	6 44	— 8
California	34.9 N.	121.0 W.	1927	Nov.	4	13 51	Hilo	5 08	— 3*
Mexico	16.2 N.	97.2 W.	1928	June	17	03 19	Hilo	8 30	0*
Aleutian Is.	51 N.	170 W.	1929	Mar.	7	01 35	Hilo	4 45	— 9*
Solomon Is.	10.6 S.	161.7 E.	1931	Oct.	3	19 13	Honolulu	7 46	—11
Solomon Is.	10.6 S.	161.7 E.	1931	Oct.	3	19 13	Hilo	8 19	—29*
Mexico	19.2 N.	104.2 W.	1932	June	3	10 37	Honolulu	7 42	+13
Japan	39.1 N.	144.7 E.	1933	Mar.	2	17 31	Honolulu	7 33	—14†
Alaska	55.5 N.	157.3 W.	1938	Nov.	10	20 19	Honolulu	5 01	— 1
Chile	31.5 S.	71.4 W.	1943	April	6	16 07	Honolulu	15 31	—24
Japan	33 N.	137 E.	1944	Dec.	7	04 36	Honolulu	9 09	—49†
Aleutian Is.	53.5 N.	163.0 W.	1946	April	1	12 29	Honolulu	4 34	— 4
Japan	33.5 N.	133.7 E.	1946	Dec.	20	19 19	Honolulu	9 32	—23†

* Computed times to Hilo were estimated with the aid of near-by time curves.
† See text for a discussion of these differences.

in the Hawaiian Islands, the observed travel time, and the difference between computed and observed travel times. The computed travel times to Hilo were estimated with the aid of near-by time curves. A number of other seismic sea waves have reached the Hawaiian Islands and the available marigrams were examined. These were not included in the table because the amplitudes, as recorded by the gages, were too small to permit the determination of the first rise or fall of the waves. The natural seiche condition at both Honolulu and Hilo was the primary reason for this difficulty.

REFERENCES

BODLE, R. R. Note on the earthquake and seismic sea wave of April 1, 1946. *Amer. Geophys. Union Trans.* 27: 464–465, 1946.

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, Comn. on Seismol. Invest. Rpt. (through 1917); Internatl. Seismol. Sum. (from 1918).

GREEN, C. K. Seismic sea wave of April 1, 1946, as recorded on tide gages. *Amer. Geophys. Union Trans.* 27: 490–500, 1946.

HECK, N. H. List of seismic sea waves. Union Geodesique et Geophysique Internatl., *Ann. Com. pour l'Etude des Raz de Marée*, no. 4: 20–41, 1934.

INTERNATIONAL SEISMOLOGICAL SUMMARY. See BRITISH ASSOCIATION.

JAGGAR, T. A. The great tidal wave of 1946. *Nat. Hist.* 55: 263–268, 1946.

MACDONALD, G. A., F. P. SHEPARD, and D. C. COX. The tsunami of April 1, 1946, in the Hawaiian Islands. *Pacific Sci.* 1: 21–37, 1947.

POWERS, H. A. The tidal wave of April 1, 1946. *Volcano Letter* (Honolulu), no. 491: 1–4, 1946.

UNITED STATES COAST AND GEODETIC SURVEY. *Manual of tide observations.* iv + 92 p., 1 pl. Spec. Pub. 196, Washington, D. C., 1941.

——— *United States earthquakes, 1939.* iii + 69 p., 1 pl. Serial 637, Washington, D. C., 1941.

——— *United States earthquakes, 1943.* iv + 49 p., 2 pl. Serial 672, Washington, D. C., 1945.

——— *United States earthquakes, 1944.* iv + 43 p., 2 pl. Serial 682, Washington, D. C., 1946.

NOTES

New Botanical Bibliography of Pacific Islands by E. D. Merrill

BECAUSE OF ITS GENERAL INTEREST to scientists, attention is called to a botanical bibliography just published which was prepared by Dr. E. D. Merrill of the Arnold Arboretum, Harvard University.

The present edition, which follows two earlier ones published in 1924 and 1937, contains 3,850 author entries of works printed between 1773 and 1846. The area covered is primarily the islands of the Pacific lying between 30° N. and 30° S. latitude, and extending from Juan Fernandez and Hawaii in the east to the Carolines, Marianas, New Caledonia, and the Santa Cruz Islands in the west. The bibliography is enriched by concise abstracts for each entry. The classified subject index, added by Dr. E. H. Walker of the Smithsonian Institution, is of great value, giving ready reference to all articles published on any particular botanical subject or area.

The full reference to the volume follows:

MERRILL, ELMER D. *A botanical bibliography of the islands of the Pacific;* WALKER, E. H. *A subject index to Elmer D. Merrill's "A botanical bibliography of the islands of the Pacific."* U. S. Natl. Mus., Contrib. U. S. Natl. Herbarium 30 (1). 404 p. Washington, D.C., 1947. Published and sold by the Supt. of Documents, Govt. Printing Office, Washington 25, D.C. Price $1.00.

Scientists and the Fortieth Anniversary of the University of Hawaii

THE UNIVERSITY OF HAWAII, at a celebration on March 13–25 of the fortieth anniversary of its founding in 1907, presented to the campus and community of Hawaii many programs of interest to scientists. To carry out the theme of "The Pacific Era and Higher Education," a number of eminent men were brought to Hawaii by President Gregg M. Sinclair to give addresses; the program also offered exhibits, panel discussions, and the installation at the University of a chapter of Sigma Xi, national scientific fraternity.

Participants in the program included Dr. Karl T. Compton, president of the Massachusetts Institute of Technology; Dr. Charles Seymour, president of Yale University; Dr. Howard L. Bevis, president of Ohio State University; and Dr. Harlow Shapley, director of the astronomical observatory at Harvard University, national president of the American Association for the Advancement of Science, and national president of the Society of the Sigma Xi.

Dr. Compton, during the period, spoke on the following topics: "Importance of Technological Progress to the Pacific Society," "Five Atomic Bombs and the Future," and "From the Threshold of the Atomic Age." Dr. Seymour spoke on "Science and Men in the Pacific." Dr. Shapley spoke on "The Expanding Universe" and "Science in This Day," and together with Dr. Compton acted as installing officer for the new Sigma Xi chapter. Other events included a luncheon of the Volcano Research Association, an official visit to the Bishop Museum, and addresses by the visitors before both houses of the Territorial Legislature.

Natural science exhibits on the campus included research carried on at the University Agricultural Experiment Station, bacteriological specimens and films, greenhouse demonstrations of nutritional deficiencies in plants, physical and chemical operations and instruments, and exhibits by the Pineapple Research Institute, the U. S. Bureau of Entomology and Plant Quarantine Fruitfly Laboratory, and the Hawaiian Sugar Planters' Association Experiment Station. The Bishop Museum offered a special exhibit of ethnographic, botanic, and zoologic collections from Pacific islands.

Charter members of the new chapter of Sigma Xi installed on March 19 were: Joseph E. Alicata, Earl J. Anderson, Harry L. Arnold, Eugene C. Auchter, John H. Beaumont, Earl M. Bilger, Leonora N. Bilger, David D. Bonnet, Robert C. Brasted, Elizabeth D. W. Brown, Forrest B. H. Brown, Peter H. Buck, George O. Burr, Oswald A. Bushnell, Walter Carter, Edward L. Caum, Harold E. Clark, Harry F. Clements, J. L. Collins, Charles Montague Cooke, Jr., Arthur Lyman Dean,

Charles H. Edmondson, Willard H. Eller, John F. Embree, Charles J. Engard, George E. Felton, Harvey I. Fisher, Theodore W. Forbes, William A. Frazier, William O. French, David T. Fullaway, Herbert E. Gregory, Rene Guillou, Christopher J. Hamre, Ernestine K. Hamre, Floyd W. Hartmann, Constance E. Hartt, Pauline Heizer, Robert W. Hiatt, Frederick G. Holdaway, Kenneth R. Kerns, Alvin R. Lamb, Maurice B. Linford, Katharine Luomala, Maude F. Lyon, Harold L. Lyon, Eugene G. McKibben, Joseph P. Martin, F. P. Mehrlich, Alice A. Nightingale, Harold S. Palmer, John H. Payne, Cyril E. Pemberton, Henry N. Peters, Charles F. Poole, Donald P. Rogers, Harold St. John, G. Donald Sherman, Christos P. Sideris, Janet M. Smith, Jared G. Smith, Carl H. Spiegelberg, Robert A. Spurr, Edward J. Stirniman, William B. Storey, Otto H. Swezey, Richard Kwock Tam, William E. Vinacke, Kenichi Watanabe, Ernest C. Webster, Chester K. Wentworth, Juliette Wentworth, John Mason Young, and Elwood C. Zimmerman.